ABSTRACT

Title of Thesis: BUILDING RESILIENCE OR BUILDING FRAGILITY? UNDERSTANDING DISASTER RESILIENCE PATTERNS IN GUATEMALA THROUGH THE ANALYSIS OF DISASTER DATASETS IN CONNECTION WITH POPULATION AND HOUSING DATA

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Master of Science, 2021.

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Guatemala is one of the most disaster-prone countries in the world due to its exposure to social and systemic vulnerabilities that often exacerbate the occurrences of multiple natural hazards and their interactions. While some research has been carried out on the physical characteristics of the natural hazards, few empirical investigations have explored how disasters have impacted and changed the social landscape and built environments at a national, departmental scale (provinces). This study sought to use archival methods to obtain data related to disaster losses, population, housing characteristics, and household resources from database archives and organizational records to compile it into a unique database and perform spatial and longitudinal analysis methods for the period between 1973 and 2018. This study has identified correlation patterns between disasters and human population rates of growth, as well as roof and wall construction materials of housing. However, correlations were not observed between disasters and essential household utilities such as drinking water supply or toilet types. The findings of this research provide insights for reducing the impact of future disasters by improving the understanding of how population and housing vulnerabilities evolve through time and may be related to the impacts of one or many disasters.

BUILDING RESILIENCE OR BUILDING FRAGILITY? UNDERSTANDING DISASTER RESILIENCE PATTERNSS IN GUATEMALA THROUGH THE ANALYSIS OF DISASTER DATASETS IN CONNECTION WITH POPULATION AND HOUSING DATA

by

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Thesis submitted to the Faculty of the Graduate School of the University of Maryland, College Park, in partial fulfillment of the requirements for the degree of
Masters of Science
2021

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Dedication

To Prof. Fernando Arévalo Franco, in memoriam.

Acknowledgements

Above all, I want to thank my advisor, Dr. Michelle Bensi, for her dedicated guidance and support in recent years. Thank you for being a fantastic advisor and mentor to me. This thesis would not have been possible if my research ideas had not found a safe place to flow and grow, guided by sound ethical, scientific, and human principles. Thank you for all your time dedicated to my research; for the dozens of meetings to follow up on my research; for helping me focus on building this thesis piece by piece rather than letting me drift away while I was having a hard time; and for your determination and conviction that I could achieve my goals.

I also want to thank the other members of my thesis committee, Dr. Kaye Brubaker and Dr. Allison Reilly. Thank you for your dedicated reading, discussion, and suggestions for my thesis.

I want to thank my research team colleagues for inspiring me to do quality research, sharing tips and tools, and giving me suggestions to improve my methods, presentation skills, and further research. I especially thank the graduate students, Azin, Constantinos, Jonathan, Kaveh, and Somayeh. I also greatly appreciate the contributions to my thesis of the undergraduate students researchers, Calvin Penaflor and Aaron Ault, for their help in the data cleaning and digitization stages and generating different graphics for data visualization.

I want to thank friends, classmates from the master's degree, and the work office for encouraging me in the most challenging moments throughout the master's degree. Special thanks to Alex, Alireza, Cadijah, Caleb, Liking, Mani, Mohammadreza, Paul, Priya, and Tong. I also want to thank my Fulbright friends at UMD, especially Bhasit, Farhad, Huma, Jacek, Jawairia, Mansoor, Nina, Néstor, and Salman. I cannot forget to thanks to Priya and Simran for the virtual writing sessions.

I want to thank the Latin American and Caribbean Studies Center for being "my other home" at UMD and providing me with a space to learn, think, discuss and organize collectively surrounded by beautiful people in a multidisciplinary environment. The contributions of the Graduate Writing Group were crucial to develop my research and prepare my defense of thesis. I give a special thanks to Ana, Britta, Cara, Daniela, Danielle, Eric, Gabrielle, Jonathan, Keisha, Kris, Lisa, Ofelia, Marco Polo, María, Mariángel, Merle, Nancy, Nohely, Sabrina and Víctor.

I wish to thank the participation of multiple Guatemalan researchers for their contributions to my thesis. Thanks to Jorge Aragón from Centro de Estudios Urbanos y Regionales of the Universidad de San Carlos de Guatemala for the discussions on my research topic and for sharing data from the 2002 Population Census. Thanks to Edy Manolo Barillas from the United Nations Office for the Coordination of Humanitarian Affairs in Guatemala for your support with data and information on disasters in Guatemala. Thanks to Agnes Soto for the encouraging words, and thanks to Gisela Gellert for creating the disaster database that I used for my analysis in this study.

I also want to thank María and Reyna, from the Kim Building services Staff at UMD, for their dedication to keeping my work environment in a hygienic condition, but even more importantly, for their friendship and for sharing with me during multiple lunch hours. Millones de gracias.

Last but not least, I wish to thank my family. To Maddie, my beloved partner, thank you for walking with me during this stage of life, for supporting me in my research, discussing ideas, solving my grammar questions, reading, editing, for helping me make hundreds of photocopies of my research bibliography. Thank you for bringing me down to earth when I was lost and tormented in the nebulous process of research and thesis writing. Your help throughout the master's program and even before starting was immeasurable.

Gracias a mis padres, Elsa Estela y Fredy; *mami y papi*; porque me lo dieron todo siempre, y por su amor incondicional. Gracias a mis hermanos, Panchito y Fredy, por ser mis amigos más amados. Gracias a toda mi familia y amigos en Guatemala, que son demasiados para mencionar acá, pero que de todas formas ya saben que les quiero.

This material is based upon work supported under a Fulbright Foreign Student Program Scholarship. The views, opinions, findings, conclusions and recommendations expressed in this publication are those of the author and do not necessarily represent the Fulbright Program of the U.S. Department of State.

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List of Abbreviations

GTM: Department of Guatemala

EPG: Department of El Progreso

SAC: Department of Sacatepequez

CHM: Department of Chimaltenango

ESC: Department of Escuintla

SRO: Department of Santa Rosa

SOL: Department of Sololá

TOT: Department of Totonicapán

QTZ: Department of Quetzaltenango

SUC: Department of Suchitepequez

REU: Department of Retalhuleu

SMA: Department of San Marcos

HUE: Department of Huehuetenango

QCH: Department of Quiché

BVZ: Department of Baja Verapaz

AVZ: Department of Alta Verapaz

PET: Department of Petén

IZB: Department of Izabal

ZCP: Department of Zacapa

CHQ: Department of Chiquimula

JAL: Department of Jalapa

JUT: Department of Jutiapa

CONRED: Guatemalan Coordination Agency for Disaster Risk Reduction (In Spanish, Coordinadora Nacional para la Reducción de Desastres).

Chapter 1. Introduction

1.1. The importance of understanding disaster resilience in Guatemala

Guatemala is one of the countries with the highest risk of disasters in the world (8th in the world and 3rd in Latin America and The Caribbean) due to its exposure to multiple natural hazards in the context of continually increasing and changing socio-environmental vulnerabilities [1–3]. Historical disasters such as the 1976 Earthquake, Hurricane Mitch in 1998, Hurricane Stan in 2006, and the 2018 *Volcán de Fuego* (Fuego Volcano) eruption are among the most devastating disasters of their kind in the recent history of the country and the region of Central America[4–9], each one of them being decisive in the subsequent development of multiple generations [10]. For instance, the Disaster Inventory System (DesInventar[1]), a disaster database used for this study, indicates that 23.73% of all the houses impacted by at least one disaster were destroyed, and 40.86% had some level of damage [1] . Table 1-1 shows the number and percentage of disaster events that (1) caused no direct damage to housing (e.g., droughts), (2) caused some level of damage to one or more houses, and (3) destroyed at least one house. Percentages are provided based on the Desinventar data for the time period 1988-2015 as well as using percentages previously calculated by Gellert & Gamarra (2003) for the time period 1988-2002. Approximately 60% of disasters in Guatemala include damage or destruction of homes.

In Guatemala, disasters often happen due to the influence of socio-economic and political factors that led people to live at a permanent risk [1,9,14]. It has not been surprising to find in the literature phrases that refer to Guatemala as an "unnatural disaster" by itself [15]; or redefinitions of disaster concepts like the 1976 "Class-quake" [16] in allusion to the unequal distribution of wealth as the reason for the causalities

[1] According to their website definition (www.desinventar.net), The Disaster Information Management System (DesInventar) "is a sustainable arrangement within an institution for the systematic collection, documentation, and analysis of data about losses caused by disasters associated to natural hazards." The DesInventar chapter of Guatemala was a database built from newspaper sources by German-Guatemalan sociologist Gisela Gellert between 1988 and 2015. DesInventar has proven, on multiple occasions, to be the most reliable source of disaster data in the region [11–13]

concentration on populations living on precarious dwellings [9,14,17]. There seems to be a general agreement in the field, particularly from a sociological approach, about the non-necessity of natural hazards for a disaster in Guatemala [18].

Table 1-1: Rates of housing levels of damage (not damaged, damaged, and destroyed) for all the disasters between 1,988 and 2,015 in Guatemala.

Description of disasters' level of damage on housing	**Quantity (from DesInventar) for the period from 1,988 to 2,015**	**Percentage (from DesInventar) for the period from 1,988 to 2,015**	**Percentages from Gellert & Gamarra (2003) for the period from 1,988 to 2,000**
Disasters did not cause direct damages to housing	3,543	35.41%	48%
One or more houses had some level of damage	2,313	40.86%[1]	28%
One or more houses were destroyed.	1,695	23.73%	24%
Total of disaster events	**7,551**	**100.00%**	**100%[2]**

A safe house should provide the living environment where physiological needs –the most basic needs– can be fulfilled [19]. However, poverty, lack of technical assessment, and qualified expert knowledge [20] caused by political negligence, corruption, and systemic racism [21–24] have historically affected the reconstruction processes of new houses after the impact of a disaster. The results from the recovery processes are manifested as new housing conditions that do not improve previously existing ones, in many cases being even worse [25]. For instance, the reconstruction processes have often restored homes in the same places where the disaster was experienced, following a traditional "back-to-normal" approach and amplifying the vulnerability conditions that caused the disaster. Besides, houses are often rebuilt with

[1] Some disaster registers of the DesInventar database would indicate that a disaster did cause damages on housing with a categorical description (i.e., "YES") instead of being numerically described. Therefore, it was assumed that these registers indicate that one or more houses had some level of damage.
[2] Gellert & Gamarra (2003) analyzed a total of 2,418 disasters that occurred from 1988 to 2000, however, did not analyze the Hurricane Mitch records (552). The author of this thesis included the 552 records from Hurricane Mitch in Table 1-1 to validate the comparison between the two periods: 1,988 - 2,015 and 1,988 - 2,000.

the same or worse construction materials and methods contributing to increasing the population vulnerabilities. In Guatemala, disasters tend to be propagated instead of mitigated.

In Guatemala, most of the disaster management decisions are often taken without having an understanding of the risk factors and conditions that create disasters [1,26]. Local and community organizations tend to be disregarded and not included in the reconstruction processes after the impact of a disaster, resulting in even more weakened and unsustainable communities that are put in positions to suffer even more after the impact of the disaster instead of being able to recover better [26–28]. The latter is often promoted by centralized and verticalized traditional disaster intervention supported by the Guatemalan state institutions (i.e., Military, Municipality Governments, and the Guatemalan Coordination Agency for Disaster Risk Reduction -CONRED-) that have not created programs to reduce important risk factors such as enhancing housing and dwelling conditions [1,29]. The limitations of the traditional disaster management practice that is mostly focused on the management of emergencies have exacerbated the vulnerabilities of the Guatemalan peoples'[1] [1,29,30] , hindering their abilities "to anticipate, cope with, resist and recover from the impact of natural hazards" [9].

The dominant vision of disasters in Guatemala magnifies the physicality of the natural hazard and disassociates its causes from the social framework. The naturalness of disasters covers most of the analysis and discourses when it comes to explaining its causalities. Under this vision, disasters are frequently described as unavoidable and unforeseeable events, consequently, creating an ideal environment for inaction, stationarity, and therefore, a permanent reproduction of risks and potential disasters.

[1] According to Celigueta (2015), as of the 2002 census, the binary classification of the Guatemalan population as indigenous / non-indigenous was abandoned, and it was reclassified by ethnicity or "people": Maya, Xinka, Garífuna, Ladino, and others. An additional classification based on the spoken language was also introduced, with characteristics similar to the one previously defined. Celigueta (2015) also pointed out the complexity of the different identities given the constant global and local evolution of indigenous representations.

The traditional risk reduction practices are not only ineffective, but also responsible for incentivizing repeating patterns of risk reproduction.

Population and housing databases are of paramount importance for the quantification of causalities during the occurrence of the disaster. In Guatemala, however, the lack of knowledge about disaster damages and causalities is often common even for local-scale disasters. For instance, in 2018, the Volcán de Fuego (Fuego Volcano)[1] exploited and razed the entire San Miguel Los Lotes[2] village after being buried by 2 to 3 meters of pyroclastic flow [6]. CONRED reported that the pyroclastic flows from the volcano caused the death of 188 people, and the disappearance of 240. However, some survivors and various civil organizations claimed that these reports were wrong, and that there were many more fatalities. Until today, the causalities report continues to raise suspicions among the population, and nobody knows with precision how much people lived in San Miguel Los Lotes before the volcano explosion[3].

While most research on disaster resilience in Guatemala has identified the natural hazards and their physical processes, few studies have explored the relationship between measurements of population and housing components, and disaster occurrences, especially focusing on the community's social and built environment, and the potential that measuring physical housing conditions and utilities has on enhancing

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[1] Volcán de Fuego (in Kaqchikel Mayan language, Chi Q'aq) is a stratovolcano in Guatemala (3763 m above sea level; 14.47°N, 90.88°W) that since 1,524 has produced over 50 explosions categorized with a Volcanic Explosivity Index of 2.0. Many researchers have inferred that the Volcán de Fuego explosion in 1717 triggered cascading disasters that ended up with the relocation of the capital city from Santiago de los Caballeros (now Antigua Guatemala) to its current location in Ciudad de Guatemala [31,32].

[2] San Miguel Los Lotes was a *caserío* (hamlet) located 5 miles below the Volcán de Fuego's crater. It used to be part of a a smaller settlement of the village of El Rodeo, municipality of Escuintla, department of Escuintla, Guatemala. It is known today as "Zona Cero" (Ground Zero).

[3] For 2018, the National Institute of Statistics (INE) reports that 810 people lived in San Miguel Los Lotes. However, the People National Register (RENAP) reports 397 people for the same village. The former corresponds to a population report projected from the 2002 census—the latter to death and birth certificates accounting. In addition to this data discrepancy between the two population registers, some local and international media also speculated that more than 3,000 people died. However, this misconception was because the media erroneously reported that the pyroclastic flow also engulfed El Rodeo village. A World Bank rapid post-disaster report confirms that El Rodeo was affected by ashfall, but not by the pyroclastic flow [6].

resilience disaster recovery. Household resilience is directly linked to protective factors that are associated to family resilience such as sets of beliefs and attitudes, daily routines and rituals, communication ways, and coping and problem-solving skills [33]. The disasters after the disaster (i.e., poverty, violence, massive immigration) will continue to increase in Guatemala if the disaster management paradigm is not switched from focusing on attending emergencies to focusing on the in-depth causalities that continue to kill people.

1.2. Statement of the Problem

Disaster management in Guatemala has shown historical flaws due to the lack of understanding of both the physical and social dimensions of its territory, and analysis of how these are affected by disasters. There is ample evidence of disaster solutions and responses that were designed to fail because they were not implemented to achieve a real reduction in population vulnerabilities [25,26,28,34]. Additionally, in Guatemala, the measurement of disaster data continues to perform poorly [1,11], making the tasks of organizations and service delivery systems even more difficult. In general, there is a lack of interest in analyzing retrospective interpretations of response activities.

Building disaster resilience, particularly household or family resilience, implies improving the understanding of the relationship between multi-hazard events and their impact on the population, especially at lower-scale definitions. However, disaster data is often low in quantity and quality in developing countries like Guatemala. The latter causes a major problem in promoting a culture of disaster management. The fragility of societies and their infrastructure is often related to the efforts made to collect, synthetize, analyze, and make available the data that is relevant to protect and enforce their life and natural systems. On the other hand, frequently, the lack of transparency (and, in some cases, honesty) by various public institutions discourages public confidence in the government's information in times of disaster. A case that serves as an example occurred recently during the first months of the COVID-19 pandemic, where the presidential commission for attention to the COVID-19 emergency admitted having "artificially modified" some data on the behavior of the pandemic with the objective of "flattening the curve" and of not showing a decrease in COVID tests performed [35,36].

Housing materials have a cultural value that is frequently ignored by in post-disaster reconstruction processes. The actors in this stage of disaster management lack mechanisms and historical data on how the infrastructure landscape has evolved -- or been involved - over time. Hence, decisions are frequently made that reduce the capacities of populations to adapt and recover better from future disasters.

Lastly, the lack of knowledge about the relationship of disasters and household utilities leads to deficient response in emergency situations. The scarcity and dispersion of information, coupled with a complex network of stakeholders, leads to responses that often ignore important factors such as accessibility to utilities (i.e. source of energy for cooking, electric connectivity, water access) and telecommunications (i.e. mobile devices, internet access, source of energy for cooking, electric connectivity, etc).

Guatemala will remain to be a disaster-prone country if the understanding of how population, and the structural, habitational, and utility housing components intertwined with the disaster impacts is not improved, and then applied to frameworks that focus on radically transform the most urgent needs of the population.

1.3. Background and Research Need

There is extensive evidence on the historical failures that stakeholders and decision-makers have promoted due to the profound lack of knowledge of the underlying conditions that cause the reproduction of social vulnerabilities and foster the risk to disasters [37]. Disasters have made vulnerable populations even more vulnerable. The reactive and short-term emergency response often lack effectiveness and transparency; arbitrary decisions that are not based on people's needs are often taken [26,38,39].There is an urgent need to change the disaster risk reduction (DRR)[1] practice by understanding and identifying patterns of the interplay between the infrastructure systems and population recovery.

Statistical information on how disasters affect Guatemala is usually provided at national scale level. This is perhaps due to the nature of most of the international databases that tend to focus on the report of only major disasters (i.e. Hurricane Mitch, Agatha Storm, 1976 Earthquake). These databases do not contribute to reflect the problem on a smaller subnational scale (i.e. departmental and municipal). There is a need to use databases that have been developed at the departmental and municipal level (i.e. censuses, disaster databases) to enhance the understanding of how disasters affect socio-spatial dynamics such as changes in population growth, interterritorial movements (i.e. from one department to another) and how these dinamics have changed through time.

Furthermore, housing reconstruction processes often ignore minimum safety, quality, and cultural adherence [29]. Future disasters endanger the people's lives and built environment, but they also put at risk the cultural and spiritual belief that their homes' material components have in their lives. It is necessary to fully understand how disasters have impacted infrastructure and housing conditions over time to improve future reconstruction and recovery processes by improving household resilience.

Lastly, emergency responders also tend to operate strategies that do not account for households' utility availability. For instance, the current COVID19 pandemic has shown how the government has failed to distribute emergency funds through their electric bill service [40]. A national survey made by the local social justice

[1] There is a wide variety of DRR definitions that keep evolving through time. The Sendai Framework for Disaster Risk Reduction 2015–2030 defines DRR as “the policy objective aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contributes to strengthening resilience. A previous definition from UNISDR defines DRR as: “[all the] actions for preventing new and reducing existing disaster risk and managing residual risk in order to raise disaster resilience and therefore achieve sustainable development (UNISDR 2009).

organization, Paraíso Desigual, revealed that in 29% of the 158 surveyed communities, respondents reported that only "a few" members or "nobody" received a code to sign up to the emergency funding program. There is an urgent need to understand the different settings of household utilities among the twenty-two different departments to elaborate and implement emergency responses that help the population of the different departments of Guatemala to thrive in times of disaster.

1.4. Purpose of the Study

The purpose of this study was to compile and analyze a set of disaster databases, housing and population censuses to understand the relationship between disasters triggered by natural hazards and a variety of housing structural, habitational, and utility components for the population of Guatemala located in the 22 different departments.

The population of Guatemala often experience severe changes in their population and infrastructure dynamics by the impact of disasters. These dynamics are related to the capabilities that households and stakeholders have to prepare, respond, recover, and adapt from hazardous events. The trend has been that disaster management has been understood as emergency management, failing in reducing the risk to disasters. Understanding the underlying conditions that shape the social and physical systems is paramount for identifying the population vulnerabilities and then incorporate solutions in engineering planning and design to foster an urgent implementation of a DRR culture.

To explore the population dynamics and the housing structural, habitational and utilities components, the researcher collected, digitized, compiled, and analyzed Guatemalan population and housing censuses from the period of 1973 to 2018. Numerical analysis tools were used to perform data analysis and visualize patterns at different time intersections. Parallelly, the researcher also analyzed three disaster datasets contained between the same period. The researcher used spatial analysis methods to reveal potential patterns of disaster occurrences and other relevant disaster statistics.

The goal of the study was to understand how disasters have transformed both the social and built environment in the period of 1973 to 2018 in Guatemala. This study also contributed to measure general population and housing characteristics that may be associated with resilience potential, particularly in developing countries.

1.5. Research Question

What can an analysis of disaster databases and Guatemalan population and housing censuses reveal about the relationship between disasters triggered by natural hazards, structural components of housing, and housing connection to services and resources on a departmental scale?Significance to the Field

1.6. Significance to the field

This study provides an important opportunity to advance the understanding of the linkages between disaster impacts on population and housing characteristics in Guatemala. This is the first study to compile a comprehensive data base addressing these areas and it also the first to undertake a longitudinal analysis that contrasts historic disasters with housing and population censuses information in Guatemala. Lastly, it is hoped that more research continues to be generated by performing analysis with the dataset created for this study.

1.7. Limitations

The analyses performed in this study are based on census information that contains some degree of error. It was out of the scope of this study to analyze errors or biases in the data. Similarly, local disaster datasets used in this study were collected by social scientist investigators using journal information that might be subject to biased information. Nevertheless, the selected datasets have performed well compared to international databases. Lastly, the data collection process was affected to some degree by the ongoing COVID-19 pandemic since the University of Maryland closed, interrupting the digitization process. Fortunately, most of the data had already been collected, and the compilation process could be performed while working remotely. Finally, this study focuses on identifying potential patterns in trends based on analysis of data. Causal relationships are not ascertain, but relationships are identified that can form a foundation for future study.

Chapter 2. Literature Review

Guatemala will remain a disaster-prone country if the understanding of how population and the structural, habitational, and utility housing components are intertwined with the disaster impacts is not improved and applied to frameworks that focus on radically transforming the most urgent needs of households.

This literature review addresses two areas related to understanding the relationship between society, the built environment, and disaster occurrences in Guatemala. Figure 2-1 summarizes the design of the strategy used to conduct the review literature of this thesis. This literature review is a concise compendium of recent and relevant scientific articles framed in terms related to the research question of this study (see Section 1.5). The first section (Section 2.1) addresses research related to (1) the comprehension of the importance of disaster data analysis, emphasizing Guatemala but considering selected other locations, and (2) how natural hazard occurrences affect population and its territory at national sub-national scales. The second section (Section 2.2) focuses on research studies about the changing relationship of the housing components to disasters resilience in Guatemala, specifically as they apply to future disaster preparedness and adaptation strategies.

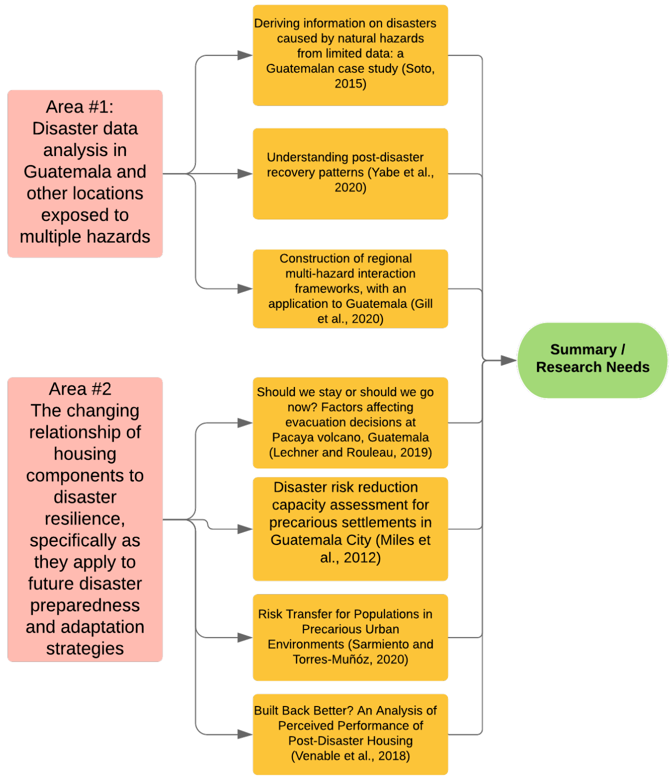

Figure 2-1: Literature Review Design Diagram

A systematic search was done using the Web of Science (WoS) Core Collection database. This engine provides capabilities for accessing scientific research through a vast extension of fields in both time and space [41]. The purpose of this systematic search was to generate a quantitative dimension of existing literature specifically to understand how available references (e.g., through basic statistics of references identified) reflect the degree to which the risks posed to Guatemala are reflected in this literature. This is motivated by the understanding that developing countries like Guatemala do not tend to generate a large quantity scientific research due to its lower education and research funding levels and low prioritization of publishing in international journals relative to other countries [42]. However, not much is known about how much research is generated on natural hazards, nor has it been quantified. A search of the terms {“Guatemala” and “Disaster”} identified only nineteen results of academic literature focused specifically on Guatemala. Similarly, additional searches were done intersecting terms of natural hazards (i.e., flood, earthquake, storm, hurricane) and “Guatemala.” Table 2-1 shows a summary of the queries results, and Figure 2-2 shows a bar plot displaying the number of articles per field of studies for the query “Guatemala AND Disasters” in the WoS website. “Environmental Studies” and “Social Sciences (Interdisciplinary)” were the most predominant subject areas for relevant literature related to the queries with the words “Guatemala” and “Disaster.”

Table 2-1: Summary of the systematic search queries performed on The Web of Science Core Collection and results

Query	Articles including the words from the query in their topics	Articles including the words from the query in their title
“Guatemala” AND “Disaster”	59	19
“Guatemala” AND “Hazard”	111	12
“Guatemala” AND “Flood”	27	3
“Guatemala” AND “Storm”	21	2
“Guatemala” AND “Earthquake”	133	44
“Guatemala” AND “Hurricane”	28	1

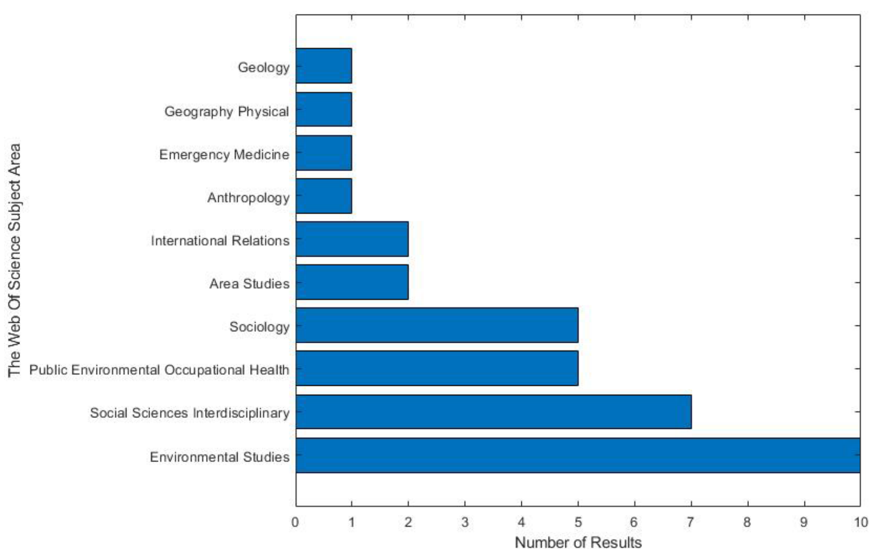

Figure 2-2: The WoS number of articles containing the terms “Guatemala” and “Disaster” per research area[1]

[1] The research areas are subject categorization schemes established by The WoS shared by all its product databases [43].

2.1 Disaster data analysis in Guatemala and other multi-hazard exposed locations

Disaster data systems allow assessments to be performed that contribute to understanding behaviors pre, during, and post-disaster. Many authors have argued about the need to better study disasters by using historical records [44,45] and comparing the impact of similar events among different societies. While this is a broad field of study, in summarizing existing works, the author of this thesis prioritized the selection of recent studies (i.e., less than approximately five years after being published) related to Guatemala or other developing countries.

Three studies were analyzed in this section related to disaster data analysis in Guatemala and developing countries. Soto (2015) [11] introduced a method to compile and process data to support analysis of disaster-prone areas at sub-national scales when data is scarce. Yabe et al. (2020) analyzes GPS data of almost 2 million mobile phones 160 days after the occurrence of 5 different disasters in 3 different countries. Gill et al. (2020) collects five types of evidence (i.e., literature, bulletins, field observations, interviews, workshops) to systematically create a synthesized visual tool to identify the multi-hazard interactions at both national and subnational scales in Guatemala. Additional details are provided below.

Soto (2015) made a detailed comparison to understand the nature of three disaster databases and designed a new class identification system to homogenize the data, prevent possible errors, and simplify subsequent analyzes. Soto (2015) compared the compiled data by type of natural hazard, causality, disaster occurrence date (month), and location (municipality). The database focused on the time frame of 2008-2011.

After the compilation was completed, a spatial and temporal analysis was performed that focused on flooding in the Río Samalá Basin of Guatemala. Four variables measured in the analysis of the Río Samalá Basin: number of disaster records and the normalized number of disaster records of hydrometeorological origin (to the total number of records) for both the DesInventar and SISMICIDE's datasets. The analysis compared the two selected datasets by considering the number of disasters by year and season (i.e., rainy and dry). Soto (2015) found a critical amount of systematic errors (e.g., misspelling of locations that could have been caused by typing errors when entering the information).

Several conclusions can be made about the process of deriving information for disasters triggered by natural hazards in a local-scale disaster in Guatemala based on the analysis of Soto (2015). First, despite CONRED and international organizations' efforts to systematize disaster datasets in Guatemala, the data systems still lack accuracy. This challenge was identified by Soto (2015) through the data quality control process, where many omissions, casual and systematic errors were found for the study case. Additionally, Soto (2015) identified that most of the inadequacies were related to data spatial resolution and time. Future research could use the methods of Soto (2015) as a guide to replicate the selection and compilation of data for disaster analysis in other areas of Guatemala.

Yabe et al. (2020) [46] aimed to investigate the possibility of characterizing population recovery patterns and their heterogeneity across different disaster occurrences, explicitly focusing on the complex interactions that both the built environment and population movement have during the recovery stage. There is a general lack of understanding of how populations recover and displace after the impact of disasters. Analyzing mobile phone GPS datasets in the context of both large and local scale is an alternative to study population recovery and displacement patterns.

Yabe et al. (2020) analyzed mobile phone GPS datasets from the US and Japan, covering approximately 1.9 million people over six months. Yabe et al. (2020) selected five disasters in the USA, Japan, and Puerto Rico: Hurricanes Maria and Irma; Tohoku Tsunami; Kumamoto Earthquake; and Kinugawa Flood. Longitudinal population recovery patterns were analyzed in affected areas at a scale of local government units –LGU's– (e.g., counties, cities, wards). More than 200 LGU's were analyzed distributed among the five different disasters in the US and Japan. Mobile location information (time, longitude, latitude) was obtained from 3 different phone companies –after previous users' agreement for research purposes. GPS information was clustered, and as a result, 1.9 million users were estimated to be living in the affected areas. To determine if mobile phone users' information could represent the entire population, Yabe et al. (2020) made correlations between the census population and the number of affected mobile phone users in each LGU. Additional regression analysis and goodness of fit methods were made to determine "short-term fluctuations," general trends of population recovery patterns. The period of analysis for the recovery time was limited to 160 days due to data limitations.

Yabe et al. (2020) designed a population model by creating a negative exponential function to relate displacement distance and duration after disasters. To understand the spatial heterogeneity in population recovery, Yabe et al. (2020) selected five independent variables based on socioeconomic data for the regression analysis: population, median income, housing damage rates, power outage recovery time, and connectedness to surrounding cities. The dependent variables were the displacements rates at day 0 and day 160 described as D0 and D160.

Some of the elucidations Yabe et al. (2020) generated were related to connecting socioeconomic inequalities impact (i.e., urban and rural differences, median income, closeness to wealthier cities) on the disaster recovery performances. A negative exponential function was used to relate displacement distance and duration after disasters.

The results indicated that median income and displacement distance had a strong correlation. The communities with more massive displacements after the impact of a disaster were often the ones with lower incomes; however, connectivity to wealthier cities also played an important role. Additionally, median income and housing damage rates had implications for elucidating insights on long-term displacement dynamics: the implication was that to more income, more efficient evacuation. Moreover, the analysis indicated that recovery time was faster for cities that were connected to wealthier cities. Finally, a regressional analysis of the variables on different time points showed that the infrastructure recovery variables were the ones that became more significant as time after the disaster elapsed.

These results added to the rapidly expanding field of human mobility patterns modeling and simulation after disaster occurrences. One of its most important contributions was enhancing the understanding of spatial heterogeneity in population displacement and recovery patterns reflected through the socioeconomic aspects variability between different local government units. Future research should consider including structural components to further explore the role of infrastructure recovery on short-term and long-term displacement. For instance, a model can incorporate the dwelling construction materials to observe the impact that these variables have on population recovery patterns. Reconstruction is a complex process that not only depends on socioeconomic variables but also cultural aspects such as construction materials availability or the predominance of a housing type due to temperature differences (i.e., concrete two-level houses over one-floor bamboo huts).

Countries exposed to multiple hazards, like Guatemala, are often also exposed to hazard interrelationships that result in concatenated events. These events can occur simultaneously or consecutively. Communities and stakeholders often lack the tools and frameworks to identify and analyze the potential disasters that can be unchained from a previous single event, being unable to reduce the risk to more immense tragedies. A systematic identification and characterization of potential hazards interactions could contribute to enhancing the reduction of the risk to disasters.

The purpose of the study by Gill et al (2020) [47] was to generate an example of a regional interaction framework for developing countries exposed to multi-hazards interactions, and study if a similar approach had the potential to be replicated in other locations with different hazard settings.

The study took place in Guatemala, where a combination of different sources of information was required for the development of the regional multihazard framework, such as international and local publications and reports, field observations, stakeholder interviews, and one general stakeholders' workshop. Some of the local actors that participated in the study were CONRED, INSIVUMEH, USAC, and other local and international NGO's.

The nature of the evidence collection was, in part, exploratory (i.e., through searching peer-reviewed articles) and qualitative (i.e., interviews with stakeholders). The combination of approaches added to the variety of information sources allowed Gill et al. (2020) to develop an integral characterization of the hazards and how they interplay.

Gill et al. (2020) performed a systematic analysis of the documents that were accessible in web-portals. For the local documents collection, Gill et al. (2020) obtained over 291 information bulletins. They looked for "interaction verbs" (i.e., trigger, provoke, generate) through a keyword Boolean search in Spanish. Visual exploration of the southern Guatemalan Highlands provided context to the multi-hazardous nature of the country. Semi-structured interviews were performed to a group of 19 different local actors that belonged to the public, private, and academic sectors. Lastly, a workshop was performed with 16 stakeholders who completed two tasks: (a) a triggering hazards diagram, accounting for the 21 triggering hazards that Gill et al. (2020) had previously identified, and (b) a natural hazard interaction matrix that interrelated both primary and secondary hazards.

The systematic regional interaction framework was composed of information on individual hazards, hazard interactions, and a proper visualization framework. Gill et al. (2020) initiated their analysis with two frameworks, a 21 x 21 matrix for the national scale, and a refined 33 x 33 matrix for the southern Guatemalan Highlands. For every single case, the matrix cells were shaded to indicate the relationships based on three different categories: a) The hazards that trigger the occurrence of a secondary hazard, b) The hazards that increase the probability of a secondary hazard, c) The hazards that both trigger and increase the probability of a secondary hazard. Gill et al. (2020) then used their frameworks to analyze three different events were multiple hazards interacted extracted from CONRED bulletin information.

The results indicated that there are 50 potential hazard interactions at a national-scale, and 114 for the sub-national scale in the southern Guatemalan Highlands region. The latter was compared to three other Guatemalan regions, resulting in being the one with mostpossible interactions of hazards. Gill et al. (2020) pointed out that the hazard interactions are not necessarily triggered inside of the studied region (e.g., a volcano eruption on the south can both trigger and increase the probability of storms in other regions by modifying the local atmospheric conditions). The latter supports the need for improving the understanding of inter-territorial disaster risk reduction at sub-national scale units in Guatemala. The article shows evidence of the complex hazard interactions network; a single trigger can potentially unchain a set of other triggers that can generate multiple hazard "waves." The case studies showed that the framework effectively captures hazard interactions. However, further evaluation is needed to verify the accuracy of the framework.

The study has shown that enhancing information about regional hazard interactions can raise stakeholders' awareness to prepare and respond better for disaster impacts. Gill et al. (2020) pointed out that their study also has implications for improving land-use planning, and the communities' preparedness to disasters. However, the latter needs to be tested and monitored to be confirmed. Visual tools such as the regional multi-hazard interaction frameworks are resources that contribute to enhancing the collective learning about complex problems; the latter is vital in countries like Guatemala where community experiences tend to have a significant relevance than in more developed countries. Future research should connect the multihazard interactions framework to the social and environmental parameters that capture the population vulnerabilities at different scales (i.e., local, subnational, national). For instance, to determine how a specific simultaneous interaction of a volcano explosion and a hurricane could affect a coastal region with a high dependency ratio[1] and predominance of wood houses.

The study was limited by the absence or limited presence of representatives and stakeholders' from rural areas, as the workshops were conducted in more presence of urban stakeholders. Additionally, it would have been interesting to observe how the results would differ in different settings with stakeholders from multiple locations. Gill et al. (2020) could have enhanced their matrix by using a more reliable dataset that already accounts for a wide variety of both trigger and secondary hazards, like DesInventar. Another limitation was the lack of a sample size analysis; the selected sample size could have been too small to develop a regional hazard interaction framework. Further statistical analysis could have been done to characterize the participants of the interviews and workshops. A spatial-analysis could contribute to identify if the participants of the interviews are familiar or knowledgeable about the sub-national regions that they intended to characterize through the interviews and workshop activities.

These studies support the notion that historic disaster information can lead to thecreation of new theoretical frameworks to enhance the understanding of disaster occurrences in locations exposed to multi-hazard occurrences; ultimately, leading to a needed transformation of the field and quality of life of millions of people. Two of the analyzed articles, Soto (2015) and Gill et al. (2020), used –among other sources of

[1] The dependency ratio is a demographic measure that relates the number of those younger than 15 (children) and those older than 65 (aging population) to the "working-age" population (15-64 years old). In other words, it relates the population most likely to be economically dependent to the one most likely to be economically active. Recent studies have shown that the dependency ratio has played a determinant role to understand the relationship between economic development, disaster relief expenditure and disaster impacts [48].

information– DesInventar, a dataset that was also used in this thesis. However, the analysis they performed was limited in both time and space and failed in linking to the population livability information (e.g., dwelling characteristics, access to water, methods of the garbage disposal). The frameworks and methods employed advanced research and applications in situations where data-scarce; furthermore, they achieved to identify a part of the processes causing the risk to disasters. However, their work is still too focused on the "naturalness" of the phenomena, therefore failing in linking social characteristics that exacerbate the hazard exposure and trigger disasters. Yabe et al. (2020) included variables that relate the disasters to societal factors and their built environment. However, their model accounts for conditions created after the impact of the disasters (i.e., housing damage rates), but excluded variables that could have further explain recovery mechanisms (i.e., dwelling characteristics, housing utilities). The latter would have been important to enforce the connection between disaster recovery dynamics and socioeconomic inequalities.

2.2 Structural and habitational housing components, and disasters

During the impact of a natural hazard, such as a volcano explosion, the people living within the danger zone generally focus on factors that determine whether or not to evacuate to protect their lives and their material, cultural and spiritual goods. Different perceptions of social and environmental hints influence how people react and decide whether to evacuate. The reasons why people choose to evacuate are frequently understudied. Surveys on past and future evacuation decisions are one method that could be implemented to enhance the understanding of how people ponder their evacuation decisions.

The purpose of the study by Lechner and Rouleau (2019) [49] was to determine the factors that are involved in the decision process of the population that choose to remain in the hazard area and not evacuate, to contribute to the reduction of future causalities in the Guatemalan volcano environments (Lechner and Rouleau, 2019).

The study took place in the Volcán de Pacaya (Pacaya Volcano) region in Guatemala. Lechner and Rouleau (2019) used a “systematic random sampling” to choose the participants of the study. A total of 172 randomly selected surveys to households from almost two-thirds of the communities located within a 5 km radius from the volcano. Lechner and Rouleau (2019) focused on surveying households that experience the 2010 Volcán de Pacaya eruption. Two-thirds of the participants were female, and one third were male.

The surveyed contained 29 questions distributed in six different categories: evacuation, risk perception, preparedness, past experiences, future intentions, and household characteristics. Given low literacy rates, a 5-point scale response format was implemented. The major target was to capture –through yes/no questions– the dependent variables related to past evacuation behavior and future intentions.

The answers were collected in the field and then digitized following a previously established scheme. The surveys were made door-to-door; however, surveys were also made on public environments outside of the respondents’ houses. According to Lechner and Rouleau (2019), the latter allowed for a more relaxed development of the survey. Rigorous procedures were made to reduce human-made mistakes (i.e., expert content, and language reviews). A sample representativeness test was performed, followed by a detailed characterization of the responders.’ Traditional hypothesis tests were performed to observe differences between the respondents’ evacuation experiences, behaviors, and future intentions. To analyze which differences matter the most, Lechner and Rouleau (2019) performed a binary logistic regression[1].

There were two sets of dependent variables for two different regressions: First, the respondents’ 2010 evacuation status, and second, the respondents’ future intentions to

[1] Binary logistic regressions are used to predict the relationship between predictors (independent variables) and a binary predicted variable (dependent variable).

evacuate. Portions of explanatory variables were progressively added following a nested regression approach (clustering set of choices into an "x" number of sets and allowing correlations between them) in this order: household demographics, the respondent's 2010 evacuation experience, respondent's self-ranked evacuation decision-making criteria, risk perception, evacuation perception, preparedness, and trust –the latter was only added for the future intentions model. Lechner and Rouleau (2019) reported the coefficient of determination values (r-squared) for the two regression models; however, they did not report the standard error ratios to measure the models' accuracy neither the rationality criterions (i.e., intercorrelation matrix, partial regression intercept).

The statistical significance results indicated that the most important factors for the respondents' evacuation decision-making are their own capabilities ("health and physical abilities"), the official warning messages, and manifestations of the imminent disaster. The least important factors were the need to protect one's own home –and animals or plants–, the feeling of safety in one's home and warning messages from friends and family. Lechner and Rouleau (2019) suggested that the respondents' are divided between the importance of protecting one's home and protecting from looters in case they decide to evacuate. Additionally, the surveys showed that 41% of the households did not fully evacuate from the 2010 Volcán de Pacaya eruption, and only 54% showed intentions to evacuate in potential future similar events.

These findings suggest that past experiences with evacuations in disasters do not necessarily translate into an increase in the intentions to evacuate in the future; neither does it increase mitigation and preparedness efforts. Lastly, this study's contribution has been to confirm the need for authorities to better inform populations at-risk to volcano explosions of the imminent impact of the hazard, as this information has proved to save future lives by potentially triggering more decisions to evacuate. Future research could consider how the population perceives one's housing infrastructure (i.e., roof and wall materials) as a factor for deciding whether to evacuate or not in case of a disaster. A limitation on Lechner and Rouleau (2019) lies in the fact that the intercorrelation between their predictors (the regression independent variables) were not reported. The latter potentially leads to unstable regression estimates, ultimately achieving to misrepresent the statistical significance of the predictors due to an inflated high correlation. Notwithstanding these limitations, the study suggests that the methods used can contribute to understanding how households understand risk regarding both the hazard and the act of evacuating.

Informal settlements in developing countries like Guatemala are often vulnerable to natural hazards. Achieving disaster risk reduction depends not only on residents of the informal settlement but also on a complex web of institutional relationships and multiple political and economic actors at various scales. An institutional capacity analysis from the perspective of the informal settlements –also called situation assessment– could improve our understandings of how DRR strategies interplay with settlement residents and how these strategies could be improved.

Guatemala's precarious human settlements manifest a complex intersection of social, political, economic, and humanitarian crises; they have spread mainly after historical disasters related to the impact of a natural hazard (e.g., the 1976 earthquake, Hurricane Mitch), and the internal armed conflict [50–54]. The study by Miles et al. (2012) [30] aimed at landslide and flooding hazards within precarious human settlements in the Guatemalan Metropolitan Area (AMG, acronym in Spanish). In Guatemala, as defined by Miles et al. (2012), –informal settlements construction tends to be erratic, and houses are "structurally unsound." The study sought to assess the "social relations and structures of domination" between actors that reduce risk to disasters (Miles et al., 2012).

The study by Miles et al. (2012) [30] took place in the AMG, specifically in the communities *Las Brisas* and *Unidos Ocho de Marzo* from the El Mezquital town of the municipality of Villa Nueva at the south of the AMG. Collected data included 65 household surveys, focus group discussions, photographs, and visual assessments.

Lastly, interviews were conducted with local stakeholders from academia, government, and non-governmental organizations. The interviews were open-ended; the respondents spoke about informal settlements and their interplay with natural hazards and DRR actors and stakeholders. The focus group meeting consisted of one community event where the population from the two pilot communities participated. Activities focused around settlement maps where participants discussed the current problems and potential solutions to their daily dynamics with the risk of disasters.

The study assessment applied a combination of a theoretical framework to understand hazards, vulnerability, and risk developed by Wisner et al. (2004) [55] and actor-network theory (ANT) that provided insights for "identifying, synthesizing and analyzing important actors and the flows between them." The ANT generates flows that reveal the actors' network connections.

As a result of the methodology used, a network diagram of major actors involved in the AMG was generated. The network diagram identified three different actors; government, non-government, and residents; and three different flows; financial, oversight, and services. No information was found about the survey participants' characterization. The study also lacked a description of how the data were analyzed (i.e., procedures for interview transcription, organization of field notes from the visual assessment, and data coding methods).

On the whole, the participants demonstrated that the informal settlements have a lot more access to both the NGOs and the commercial sector –informal and formal– than they do to the central government. The network also identified that the NGOs' access is limited to "some" individual settlements and that they not necessarily contribute to disaster risk reduction in their communities. Additionally, informal settlements lack access to economic resources, limiting their chances of improving their house infrastructure. Regarding the institutional effectiveness and durability, it was interesting to see that 48% of the surveyed households stated that "the government had not done anything to help reduce their disaster risk". Only 5% stated the latter for NGOs, and only 3% stated that "households themselves should support DRR efforts" [30].

Several conclusions can be made about the institutional analysis of actors' in the AMG. First, informal settlements' household scarce links directly connect them to common financial resources (e.g., central appropriations, taxes, grants, donations) and regulatory oversight relationships (e.g., land use restriction, taxes, contracts). The latter is supported by the survey results on institutional effectiveness and durability. In general, the study showed that there are paths built for enforcing DRR practices; however, there should be a significant effort to ensure that the households "have access to and control" the money, services, and oversight flow [30]. For future research in this area, a more in-depth exploration should be made about the complex household category of informal settlements, and how their access to essential utilities and housing structure shape the relationships among themselves and with DRR actors.

A limitation observed in Miles et al. (2012) was the absence of criteria to explain how the chosen sample size was adequate to design the network of actors. Additionally, Miles et al. (2012) did not report response rates and how this factor could affect their analysis. Despite its limitations, the study certainly adds to our understanding of disaster risk reduction capacity in the AMG through the generation of an actors' network as a comprehensive tool for community resilience.
The vast majority of the marginal urban communities' experience urban precariousness through low quality of housing material and a lack of access to utilities, among other factors associated with living on the poverty line. The latter causes a major exposure and risk to disasters. Risk transfer mechanisms and instruments could contribute to support the efforts to achieve a sustainable reduction of the physical and social vulnerabilities in precarious urban settlements.

The purpose of the study by Sarmiento and Torres-Muñoz (2020) was to investigate how risk-transfer options can reduce the risk to future disasters of precarious and urban marginal communities in different Latin American cities', specifically targeting to the application of "risk transfer mechanisms where DRR measures had been implemented for earthquakes and landslides" [56].

Sarmiento and Torres-Muñoz (2020) used information extracted from the "2018 Neighborhood Approach for DRR programming evaluation" performed in four Latin American cities (LAC). The participant countries were Perú, Colombia, Guatemala and Honduras; and the cities chose were Distrito de Independencia, Medellín, Mixco, and Tegucigalpa, respectively. The criteria for selecting the cities was that they had to have exposure to earthquake and landslide risks, and a "high level of precariousness" [56]. Sarmiento and Torres-Muñoz (2020) made a comprehensive literature review to enhance their understanding of risk transfer mechanisms for marginalized communities and identify case studies. Then, pure risk premiums were extracted from the 2018 study that characterized physically and socioeconomically and assessed the risk to catastrophes of the four LAC.

Their systematic search for the literature review consisted on two filtering stages with different inclusion criteria (i.e. geographic area, target on vulnerable populations, implementation in the last 15 years). In total, Sarmiento and Torres-Muñoz (2020) extracted 12 articles from the initial 7850. The analyzed literature describes experiences with collective home insurance, individual and collective microinsurance and parametric insurance, among others. Regarding the pure risk premium (PRP), Sarmiento and Torres-Muñoz (2020) estimated it by analyzing individual hazards from a previous catastrophic risk assessment and a precariousness index. Probability density functions (pdfs) that associated each hazard event and their vulnerability were developed to calculate probabilities of exceedance and obtain the Average Annual Losses. Lastly, Sarmiento and Torres-Muñoz (2020) estimated insurance premium per family to ease the comparison among the 4 different cities.

As a result from the literature review, the risk transfer instruments, and the catastrophe risk assessment, Sarmiento and Torres-Muñoz (2020) proposed three risk transfer options: (a) a collective voluntary insurance, (b) credit for structural retrofitting with comprehensive housing insurance, and (c) and hybrid parametric insurance. The three options where compared between the four cities, being the collective voluntary insurance the one that had more limitations for it applicability –the insurance prime is voluntary and this decreases its feasibility. However, the second option demonstrated to be more feasible than the first one; described by Sarmiento and Torres-Muñoz (2020) as "risk transfer with the housing retrofits financed by low-interest loans and covered by insurance at a cost of 1%" [56]. Lastly, Sarmiento and Torres-Muñoz (2020) believed that the hybrid parametric insurance could be implemented by the private sector, however it would require deeper exploration on how to stimulate the community involvement.

The case studies proposed by Sarmiento and Torres Muñoz were analyzed from the perspective of nine features that, according to previous studies, risk transfer mechanisms must have: address a variety of hazards; reduce disaster impact on income and socioeconomic development; contribute to residual risk coverage; help affected communities to re-establish their livelihood activities; promote risk mitigation; reduce government resources burden associated to disaster response and recovery; cost-effectiveness; provide opportunities for public-private partnerships and scalability.The results of Sarmiento and Torres-Muñoz (2020) strengthen the arguments about the precarious insurance culture in developing countries. Additionally, Sarmiento and Torres-Muñoz (2020) argue that funding and risk transfer strategies are necessary to achieve comprehensive risk management aligned with sustainable development. Sarmiento and Torres-Muñoz (2020) partially addressed cost-effectiveness and scalability due to data limitations.

After a disaster, governments and organizations in charge of promoting post-disaster recovery in communities with socioeconomic impacts and damage to their housing infrastructure have almost unanimously adopted the "build back better" criterion and used it as a discursive practice. On the other hand, these new constructions' potential beneficiaries have expectations based on multiple socioeconomic factors and variables of damages and losses after the disaster, which influence their perceptions towards new constructions or repairs and how these will affect their future lives.

Venable et al. (2020) designed questionnaires distributed in March 2018 by trained interviewers in a Central Philippines community that received housing assistance after the devastation of Typhoon Haiyan (also called Typhoon Yolanda) in 2013. The questionnaire sought to explore the community's perceptions regarding the performance that new houses would have in the event of a typhoon similar to that of 2013 or a recent severe earthquake. The survey mainly focused on the respondents' perceptions of seven traditional housing components (foundation, floor, walls, roof, the structure supporting the roof, windows, doors, and household contents). The interviewers used visual material to better exemplify the damage scenarios. The survey's independent variables were gender, education, income, prior construction knowledge, and household satisfaction [57].

The results found that prior knowledge in construction and gender were decisive in their relationship to the formation of the perception of structural housing units' performance for the event of either a typhoon or an earthquake. However, the variables of income or education level did not have a significant effect. Another interesting finding was that, on average, the respondents perceived the typhoon more devastating than the earthquake and that women perceived a better performance of homes than men. The findings of Venable et al. (2020) suggest multiple challenges that organizations and governments participating in the post-disaster housing assistance program should consider improving the levels of satisfaction and safety of homes in the face of future disasters. Venable et al. (2020) contributions point out a direction to improve the understanding of how stakeholders can prepare to help better the populations' beneficiaries of housing assistance programs.

Chapter 3. Methodology

The following research questions were addressed in this study:

- How do the combined analysis of disaster databases, and population and housing censuses contribute to improving the understanding of the disaster impacts in Guatemala?
- Are the transitory population and housing patterns developed in Guatemala (potentially) due to disaster impacts?

The purpose of this research was to analyze disasters and their impact on population and housing. This study followed a mix of archival research design and exploratory data analysis methods. For this reason, it was decided to explore quantitative information in the form of databases containing information on (a) disasters caused by the impact of natural hazards in Guatemala, and (b) population and housing censuses.

Data was obtained from disaster databases as well as population and housing censuses and was subsequently analyzed with methods that allowed an empirical and descriptive interpretation. A wide variety of database archives and organizational records were identified and selected to systematically collect, classify, organize, digitize, depurate, and tabulate the data needed for this study. The goal was to build a single database to ease subsequent data processing using spatial and longitudinal analysis methods. Additional information regarding design of the archival database is provided in Section 3.1 Archival Design. Information about methods used for the spatial and longitudinal analysis is provided in Section 3.2.

3.1 Archival Design

Two types of archival research were performed in this study: database archive [Section 3.1.1] and organizational records [Section 3.1.2]. Database archives are usually collected and compiled by governments, international organizations, and academic institutions, and they tend to cover wider periods and larger populations. Organizational records are sources of information that contain data in physical (i.e., printed documents and records) or obsolete (i.e., floppy disks and microfilm) formats that have not been digitally processed to be used as databases. Organizational records require an additional effort, and sometimes authorizations, to be processed and used as databases [58].

All the disaster information compiled in this study was obtained from database archives. However, a mix of database archives and organizational records were needed to obtain the population and housing censuses. As Vogt et al. (2012) state in their archival designs guidebook: "Archival researchers collect data they have not generated" [58]. For this reason, it was imperative to be careful and critical of the information obtained. The archival work contains a high degree of human intervention; therefore, this study is unlikely to be free of human errors. The procedures were documented to make the investigative process transparent and infer which stages contain the greatest degree of risk to human error.

Figure 3-1 provides an overview of the process used to prepare the database used in this study through a flowchart that was iterated a total of times equivalent to the number of years of the population and housing census since 1880 (i.e., 1880, 1893, 1921, 1938, 1949, 1964, 1973, 1981, 1994, 2002) [59–80, 80–87]. The process began with the search for census and disaster databases. In the few cases where the search of databases was successful, a systematic review was carried out directly and, when necessary, translations from Spanish to English were completed. Then the various stages of compilation were carried out, including monitoring and quality control. In the cases where the search for databases did not generate positive results, the search for organizational records proceeded. First, openly available documents on the web were searched; if unsuccessful, physical documents were requested and explored through the University of Maryland (UMD) Interlibrary Loan Services. The books and reports with data were first digitized (i.e., scanned). Subsequently, optical character recognition (OCR) and, mostly, manual manipulation (i.e., typewriting from the digitized document to Excel) was used to tabulate the data. Lastly, the tabulated data was systematically reviewed, and the same procedures and criteria already described for compiling the databases were applied. The Sections that follow provide information on selection of datasets (Section 3.1.1), collection of census information (Section 3.1.2), and processing of census information (Section **Error! Reference source not found.**).

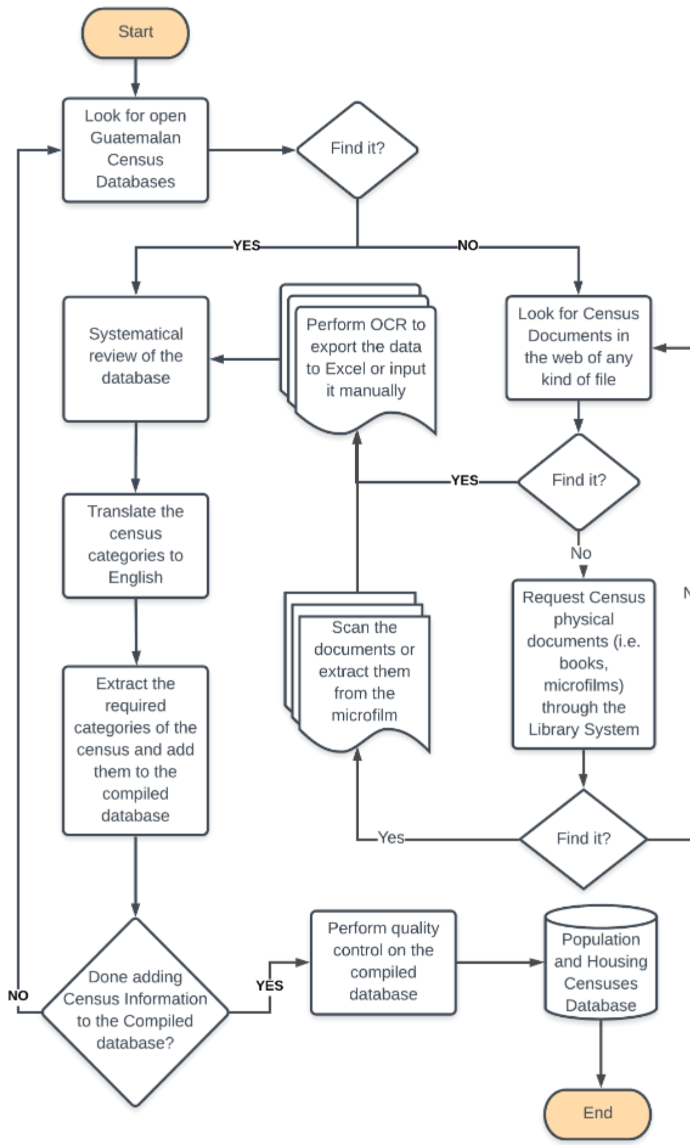

Figure 3-1: Flowchart of the database collection process

3.1.1. **Disaster Dataset Selection**

Three specific criteria were used for the selection of disaster databases. The aim was to find disaster information that spanned a period long enough to analyze the impact of various disasters. For instance, the database needed to reflect major historical disasters such as the 1976 Earthquake or Hurricane Mitch (1999). The second important criterion was to have a spatial distribution on a sub-national scale: community, municipal, or departmental. The third selection criterion was that the database should be freely accessible.

Google and Google Scholar portals were used to search databases nationally and internationally. The search began in Spanish, intending to find local databases. The initial search results were scant, and only one database was found. Extension of the search in English was more successful, and identified at least four websites containing information related to disaster databases with information of relevance to Guatemala. Except for the DesInventar database, which was already known after reading Gellert & Gamarra (2003), all the databases were internet search results using key terms such as "disaster datasets + Guatemala" or " natural hazards datasets + Guatemala. " [1].

Four databases of relevance were identified:

1. Information Management System in Case of Emergency or Disaster (SISMICEDE-CONRED)
2. The International Disaster Database (EM-DAT)
3. Index for Risk Management (INFORM)
4. Inventory system of disaster effects (DesInventar)

A summary of the disaster databases is shown in Table 3-1.

It was interesting to note that there is a predominance of monitoring and managing disaster information by international institutions and organizations. Some databases managed by international organizations contain information on disasters dating back to 1900. While CONRED, the national institution of Guatemala in charge of disaster management, only began to build its database in 2008 [11].

Table 3-1: Summary of the disaster databases collected for this study.

No.	Name of the database	Acronym	Institution	Place of Origin
1	Information Management System in Case of Emergency or Disaster	SISMICEDE[88]	CONRED	Guatemala
2	The International Disaster Database	EM-DAT[89]	Center for Research on the Epidemeology of Disasters (CRED), Université catholique de Louvain.	Belgium
3	Index for Risk Management	INFORM[90,91]	European Comission, Joint Research Centre	Europe
4	Inventary system of disaster effects	DesInventar [92]	Corporación Osso	Colombia

It is important to emphasize that the purpose of this study was not to assess each of the databases' quality but rather to systematically integrate information from the databases. Nonetheless, some observations were documented related to the similarities and discrepancies between the databases.

The studies described in Chapter 2 helped informed selection appropriate databases for this study from the perspective of spatial resolution. Gellert & Gamarra (2003) note that the analysis of disasters in Guatemala is usually carried out only on a national scale [1]. The interest of this study is to analyze the country's entire extent broken down by provincial sub-division. Thus, it was important to explore the spatial resolution of available data in each database. Table 3-2 summarizes the spatial and temporal distributions of the candidate disaster databases.

Table 3-2: Spatial and temporal distributions of candidate disaster databases .

Database	Time period	Location refinement
SISMICEDE	2008 – current	Geographical coordinates
EM-DAT	1900 – current	Only national scale
DesInventar	1988 – 2015	Municipal and Departmental sub-national scales
INFORM Subnational: Guatemala	2017	Municipal and Departmental sub-national scales

Following the initial exploration of candidate databases, the INFORM database was discarded because it consisted of an empirical index that was judged not useful for this study. The EM-DAT database was also discarded because its information is only available on a national scale. Ultimately, the DesInventar database was selected as the most promising for consideration in this study.

3.1.2. **Population and Housing Censuses Data Collection**

In addition to identification of information about disasters in Guatemala, it was necessary to determine what data was available electronically related to population and housing. The first search was carried out on the portal of the National Institute of Statistics of Guatemala (INE) –www.ine.gob.gt. This website is only available in Spanish - even though there are other recognized 24 national languages in Guatemala. The website link for population and housing,[1] redirects to a page external to the INE that is managed by the United Nations Population Fund (UNFPA). The title of this web page external to the INE (www.censopoblación.gt) announces only the last census carried out in 2018: XII National Population Census and VII Housing Census. As a result, census results for other years had to be obtained through additional search and

[1] At the time of initial access this information was found under the tab called statistical services (sub-category is called Population and Housing Census) accessible from the main screen of the portal. The latter is a link that redirects to a page external to the INE, also managed by the United Nations Population Fund (UNFPA) - the logos of both institutions are together at the top of the page.

processing efforts. Additional information related to the identification and processing of census data for 2018 and earlier years is provided in the subsections that follow.

3.1.2.1. **2018 Census**

Under the (census) 'Results' category, more than 25 files containing the census results were found related to the 2018 census of Guatemala. The summary of the information about the censuses of the year 2018 is provided in Table 3-3. The names of the files were translated into English.[1]

Table 3-3: Summary of the Guatemalan 2018 Population and Housing Census Tables

No.	Name of the 2018 census file	Size (Megabytes)
1	A1 - Population by sex, five-year age groups, and area	0.38
2	A2 - Population according to kinship with the head of the household	0.35
3	A3 - Population 10 years of age and older by marital status	0.34
4	A4 - Total population by place of birth and place of residence in April 2013	0.35
5	A5 - Population by ethnicity	0.34
6	A6 - Mayan population by linguistic community	0.37
7	A7 - Population of 4 years and older by mother tongue	0.38
8	A8_Population with Special Needs	0.35
9	A9 - Population of 4 years and older by level of education	0.35
10	A10 - Education dropout causes for population between the ages of 4 and 29 years	0.35
11	A11 - Population 7 years of age or older by literacy, school attendance and place of study	0.35Mb
12	A12 - Population by ownership of mobile devices, computer and internet	0.36Mb
	A13 - Population aged 15 and over, economically active and inactive, inactive condition and workplace	
13	A14 - Motherhood, live births, age of mother	0.36Mb
14	B1 - Household statistics	0.37Mb

[1] The results of the censuses are distributed as as three tables: Table A, Table B, and Table C. The files cataloged as Table A describe categories related to population data. Tables B describes categories related to housing utilities and habitational conditions. Table B provides information related to housing types, density and utilities' access Tables C describe categories related to dwelling types and materials. A total of 14 Tables A, 8 Tables B, and 3 Tables C were found. The files are only in Microsoft Excel format (.xlms).

15	B2 - Residential Water Use	0.36Mb
16	B3 - Housing by sanitation access	0.35Mb
17	B4 - Housing by energy source	0.34Mb
18	B5 - Housing equipment, facilities, material	0.36Mb
19	B6 - Housing by garbage disposal method	0.36Mb
20	B7 - Housing by rooms number	0.34Mb
21	B8 - Housing typology	0.36Mb
22	C1 - Dwelling types and occupation conditions	0.34Mb
23	C2 - Housing by walls and roofs construction material	0.35Mb
24	Cuadro C2 - Viviendas particulares por material predominante en las paredes exteriores y en el techo	0.36Mb
25	C3 - Housing by floor material	0.35Mb

Each of the 25 downloaded files was systematically scanned to determine whether the information was complete and that there were no apparent errors that warranted discarding a file. Each Excel census file contains two tabs, one with department information, and the other with municipality information. One of the main revisions was to make sure that the names of the departments, municipalities, and their respective codes were complete and that there was uniformity throughout the files. Additionally, documents attached to the census files (i.e., census taker's manual, census ballot, final results report, and glossary) were also reviewed to understand the census categories better.

It was not the focus of this study to determine or analyze the census results or the veracity of its data. However, the author of this thesis considers it relevant to mention the controversy that the 2018 census generated in various sectors of the Guatemalan population, particularly those related to the accounting of the country's total population[1] [93]. Evidence suggests that population dynamics, such as the Guatemalan high undocumented migratory flow (especially from Guatemala to the U.S.)[2], have

[1] The 2018 population census results indicate that Guatemala has a total population of approximately 14.9 million people. However, the national registry of persons (RENAP) indicates 20.2 million in its accounting. Finally, a projection from the previous census of 2002 estimated that Guatemala in 2018 would have approximately a population of 17.8 million. [93]

[2] The US Census Bureau estimates that more than 1.5 million Guatemalans live in the US in 2018. Guatemalans are the third largest Latin American population in the US behind Mexico and El Salvador. [48].[94].

consequences in the census results and, therefore, subsequent uses for analysis and planning of public policies [10,95]. Massive migrations could be linked to historical disaster impacts, as well as to future disaster reduction in Guatemala [10,25,96–99].

3.1.2.2. **2002 Census**

The search for census information for years prior to 2018 was continued; however, no more information was found on the INE website. It was determined that it was necessary to continue searching for other institutions or organizations that work in Guatemala.

Systematic searches were carried out on the websites of the University of San Carlos de Guatemala (USAC) and its library. The results were unsuccessful, and it was determined that the USAC does not have any database - of any kind - that is public and easily accessible for research. It was fortunate to have the collaboration of Jorge Aragón, a researcher at the USAC Center for Urban and Regional Studies (CEUR-USAC). Through this collaboration, it was possible to obtain digitized information from the 2002 Census. This information was shared via email from the CEUR-USAC offices on the USAC central campus in zone 12 of Guatemala City.
The digitized information from the 2002 Census was contained in 3 text files (file extension .txt). An exhaustive review of the files was then carried out under the criteria described for the 2018 Census. It was determined that the information was entered irregularly, using multiple styles of data entry. Additionally, it was found that the information was incomplete and that many of the categories were not part of the files. It was concluded that it was necessary to corroborate the digitized information with real information. Additional information related to the data collection for the censuses from 1880 to 1994 is shown in Section 3.1.2.3.

3.1.2.3. **1880 – 1994 Censuses**

The search for population censuses in Guatemala was complex due to the lack of information regarding the documents' existence. As mentioned in the previous section, the INE only has the database corresponding to the 2018 census; however, the absence of organizational documentation prior to the 2002 census was also surprising. The lack of a public registry of census records complicated archival tasks. The only historical reference of the census documents was revealed in the same official name of the 2018 census: "XII Census of Population and VII of Housing." The latter was an indicatiton that there were other eleven population censuses and six housing censuses. It was concluded that the documents' collection would have to be carried out external to the institution in charge of communicating the statistical information on population and housing in Guatemala. Information related to censuses prior to 2002 were obtained through the UMD library system. This information was obtained by searching for keywords in Spanish such as "Census" and "Guatemala." However, the searches were more satisfactory when either Roman or ordinal numerals were included following the documentary tradition of the census history in Guatemala. A total of 30 books containing around 4,500 pages were collected through the UMD Interlibrary Loan System. A summary information of the census documents collected is contained in Table 3-4.

3.1.3. **Population and Housing Censuses Data Processing**

The subsections that following outline the process used to process and aggregate census data. This includes digitizing the data collected through the UMD library system for censuses before 2002, processing the information obtained electronically for the 2002 census, and the need to homogenize information related to all censuses to generate a single database.

Table 3-4: Census obtained through the UMD Library System

Census Year	Original document name (in Spanish)	Document name translated to English	Census Type	Number of Books	Number of Departments	Number of pages
1880	Censo General de la República de Guatemala levantado el año de 1880.	General Census of the Republic of Guatemala taken in 1880.	Population	1	22	555
1893	Censo General de la población de la República de Guatemala 1893	General Census of the population of the Republic of Guatemala 1893	Population	2	22	278
1921	Censo de la población de la República 4to Censo Parte II	Population Census of the Republic 4th Census Part II	Population	1	22	617
1938	Censo urbano de la capital.	Urban census of the capital.	Population	1	1	34
1949	Sexto Censo de Población	Sixth Population Census	Population	1	22	-
1964	Censo de Población de 1964	1964 Population Census	Population	1	22	139
1973	III Censo de Habitación (Tomo 1)	III Housing Census (Volume 1)	Housing and Dwelling	1	22	603
1981	Censos Nacionales de 1981. IV Censo de Habitación. Tomo I	1981 National Censuses. IV Housing Census. Volume I.	Housing and Dwelling	1	22	257
1994	X Censo Nacional de Población y V de Habitación	X National Population Census and V of Housing	Population, Housing, and Dwelling	20	20	100 p. each book, approx..
2002	XI Censo Nacional de Población y VI de Habitación	XI National Population Census and VI of Housing	Population, Housing, and Dwelling	1	22	278
			Total	30	-	4,483

3.1.3.1. **Monitoring of the digitization process**

The process of digitizing the data was diverse not only because of the nature of the files but also because of the diversity of digitization methods required to process the data. A document was created to control the details of the process (See Appendix BB) containing information related to: (a) census year, (b) original data format (e.g., hardcopy book, .pdf, .txt,), (c) name of the file for data format (d) pages of the document to be digitized, (e) category of data to be digitized (e.g., dwelling material, water access, dwelling occupancy), (f) status of the digitization (i.e., completed, not completed), (g) name of the digitizer (person's name), (h) digitization method, and (i) special instructions. This data structure facilitated orderly and systematic progress in the complex process of digitizing data. It is necessary to emphasize the importance of having a digitization team, which acted as digitizers and data reviewer filters helping to reduce errors in document scanning and manual data entry. Table 3-5 summarizes the data digitization team that participated in this study and the role that each member had.

Table 3-5: Digitization team members and roles

No.	Team member name	Digitization Roles	Academic Affiliation
1	Sergio García Mejía	Data recognition, scanning, performing optical character recognition (OCR), manual data entry, planning and monitoring the digitization process, quality control.	UMD / A. James Clark School of Engineering / Department of Civil & Environmental Engineering
2	Calvin Penaflor	OCR, manual data entry, tabulate, and quality control.	UMD / A. James Clark School of Engineering / Department of Civil & Environmental Engineering
3	Aaron Ault	Quality control of the data, tabulating	UMD / A. James Clark School of Engineering / Department of Civil & Environmental Engineering
4	Madeline Ramey	Scanning	External collaborator with no academic affiliation.

3.1.3.2. **Optical Character Recognition (OCR) tool**

When possible, OCR tools were used to extract text characters from scanned documents (i.e., censuses books) available as PDF files. The resolution of the documents was the differential factor for the output quality of the extracted text. The OCR tool from Adobe Acrobat was used for this study [100]. The accuracy of the OCR depended mainly on three factors: the type of text generator from the original document, the quality of the scanned copy, and the editorial design of the document.

Each factor influenced the quality of the recognition result in different ways and, therefore, the usefulness that could be given to the information. For instance, the older censuses (i.e., from 1973 and 1981) were processed with a non-identified early word processor that often resulted in many errors when using the OCR tool. The print quality of the original documents could have also been a decisive factor. Additionally, the scanned copy characteristics (i.e., correct alignment, brightness) was another factor that determined the quality of the OCR outputs. Lastly, some editorial designs from the original documents might be visually attractive; however, their complexity was an obstacle for the OCR tool. The documents that performed best for the OCR tool were simple, symmetrical, clear, legible fonts, with good contrast and brightness ratios. Unfortunately, not many documents or pages had these conditions for this study. Table 3-6 shows a summary of the census documents that were processed with the OCR tool.

Despite the text identification errors by the OCR tool, the processed data was still useful. It made it possible to streamline the manual process of tabulating the data from a PDF document to a Microsoft Excel spreadsheet.

Table 3-6: Summary of the census documents that were processed with the OCR tool

Census Year	Census Type	Type of text generator	Type of document	Number of pages recognized by the OCR tool	Quality of the scanned document	Accuracy of the OCR tool for numerical characters
1973	Housing Census	Non-identified early word processor (NIEWP)	Governmental Report	318 (double pages)	Regular	Low
	Population Census	NIEWP	Report	78	Good	Low
1981	Housing Census	NIEWP	Governmental Report	485	Regular	Low
	Population Census	NIEWP	Governmental Report	252	Good	Low
1994	Housing and Population Censuses	Typewriter printer	Governmental Reports (2individual documents)[1]	962	Good	Regular
2002	Housing and Population Censuses	Computer Word processor	Governmental Report	278	Good	Regular
2018	Housin and Population Censuses	OCR processes were not needed for obtaining the information of this census year.				

[1] It was not posible to access the 1994 census document of two departments: El Progreso and Quiché.

3.1.3.3. **Manual data entry and data edit/checking**

Because some data files were only available in hard copy and due challenges with scanned documents, a significant amount of data was entered manually. In general, data was entered manually when either of the following conditions were met: (a) the OCR tool did not accurately recognize the textual and numerical characters of the original census documents available PDF, and (b) the data were only available from physical documents (i.e., non-scanned documents) or other types of computer files (i.e., ASCII files) that were challenging to import. Manual data entry represented a possible for an increase errors by human intervention but also introduced a new revision filter to reduce previous errors and serve as yet another "check" to the digitization process.

Having a digitization team with a diversified skill set and tasks reduced the risk of errors. For instance, the collaborator who applied the OCR tool and tabulated the data from a PDF file to an Excel File had to check for accuracy and make sure that the data was copied correctly. Nevertheless, a different team member would make the inverse process of checking backward that the tabulated information corresponds to the one from the original document.

3.1.3.4. **Building unified database**

The heterogeneity of data origins (See Appendix B) required a homogenization process through the construction of a database that would gather all the information that had been collected. The priority was to facilitate the analysis processes that would be carried out later. Creating this unique database was a new process that introduced another risk of human error. However, paradoxically, its construction also stimulated digitization error reduction by allowing graphical representation of the data (i.e., maps, stacked time-series graphs). Then, it was possible to correct data errors reflected as irrational behavior in the graphs (e.g., abrupt changes in linearity, unexpected peaks, outliers).

Microsoft Excel was used for the construction of a single database flat-file. Two researchers participated in the process of reviewing and building the database flat-file. A set of initial decisions were made before the construction of the database: (a) the priority was to order the information based on the 22 departments of Guatemala, (b) The censuses from 1973, 1981, 1994, 2002, and 2018 were selected because, despite heterogeneity, the author considered that it was possible to find a connecting line and homogenize the census categories after sketching matrixes to deduce similarities in data availability among the five different censuses (Table 3-7 and Table 3-8). Furthermore, the temporal space covered by the selected censuses guaranteed the inclusion of disasters for which there were records of damage and casualties at the departmental level (i.e., 1976 Earthquake and Hurricane Mitch). C) The data had to be registered in such a way as to allow its subsequent import and analysis in MATLAB.

Table 3-7: Housing structural components categories data availability by census year

Census category	Census Sub-Category	Census Year				
		1973	1981	1994	2002	2018
Wall Housing Material	Concrete	X	X	X	X	X
	Adobe	X	X	X	X	X
	Wood	X	X	X	X	X
	Bajareque	X	X	X	X	X
	Tree bark, wood/cane sticks	X	X	X	X	X
	Other / Waster Material	X	X	X	X	X
	Sheet Metal		X	X	X	X
Roof Housing	Concrete	X	X	X	X	X
	Sheet metal	X	X	X	X	X
	Cement / Asbestos	X	X	X	X	X
	Tile	X	X	X	X	X
	Thatched (straw or palm)	X	X	X	X	X
	Waster material					X
	Other	X	X	X	X	X
	Ignored					X
Occupancy condition	Occupied	X	X	X	X	X
	Unoccupied	X	X	X	X	X
	Temporary use	X	X	X	X	X
	DK/NA					X

Table 3-8: Housing utilities' data availability by census year

Census category	Census Sub-Category	Census Year				
		1973	1981	1994	2002	2018
Main source of water for consumption	Pipeline (for one house)	X	X	X	X	X
	Pipeline (for +2 houses)	X	X	X	X	X
	Public tap	X	X	X	X	X
	Well	X	X	X	X	X
	Rainwater					X
	River or Lake	X	X	X	X	X
	Spring					X
	Potable Water Delivery		X	X	X	X
	Other	X	X	X	X	X
Toilet type	Toilet (connected to drainage network)		X	X	X	X
	Toilet (connected to a septic tank		X	X	X	X
	Bucket toilet		X	X	X	X
	Pit latrine or Cesspit		X	X	X	X
	Does not have one		X	X	X	X
Lighting type	Electrical network			X	X	X
	Kerosene			X	X	X
	Candel			X	X	X
	Other			X	X	X
	Solar panel or Wind power			X	X	X
Main source of energy for cooking	Propane gas			X	X	X
	Firewood (Leña)			X	X	X
	Electricy			X	X	X
	Charcoal			X	X	X
	Kerosene			X	X	X
	Does not cook			X	X	X
	Other			X	X	X
Main way of garbage disposal	Municipal collection			X	X	X
	Private collection			X	X	X
	Burning it			X	X	X
	Burying it			X	X	X
	Littering in water bodies					X
	Littering on land			X	X	X
	Compost / Recycle					X
	Other			X	X	

3.2. Spatial Analysis Method

Spatial analysis methods were used to better understand the spatial distribution of disasters in Guatemala in the period 1988-2015. Spatial analysis methods such as queries and reasoning, transformations, and descriptive summaries were used to understand how disasters have impacted the population of Guatemala at a sub-national scale (departmental). The analysis focused primarily on reflecting disaster casualties using the DesInventar database.

As pointed out in the previous chapter, other studies have already used the DesInventar database for their analyzes, even using spatial analysis methods. The first researcher to analyze the Desiventar database was its creator, Gisela Gellert, in her study "Understanding the risk of disasters and its manifestations in Guatemala" [1]. However, spatial analyzes that differ from those previously published were developed in this thesis. Additionally, the study by Gellert covers a shorter period. At that time, the Desinventar database included only the period from 1988 to 2000 (12 years). Fortunately, the database continued to build and spanned a more significant amount of time. In this study, a time interval for 27 years was analyzed.

Chapter 4. Results and Findings

This study's results are grouped into three categories to describe patterns of population and housing structural components and utilities with the impact of disasters. In the first subsection, historical data on disasters and their impact on each of the 22 departments' populations were analyzed. The second and third subsections reflect the data analysis of the housing censuses of 1973, 1981, 1994, 2002, and 2018 that intersect with the impact of more massive historical disasters to deduce patterns related to changes in structural components and housing resources.

4.1. Historic disasters impact on population

This section describes the analysis of historical disaster data between the period 1988 to 2015 from the DesInventar database. The analysis focused on two aspects. The first captures large disasters (i.e., 1976 Earthquake, Hurricane Mitch, Agatha Storm, Stan Storm) and the second synthesizes the impact of the minor disasters that make up the majority of the database.

4.1.1. Major Disasters

Major disasters are defined here as those that have affected more than 1,000 people. Usually, they are disasters that affect multiple populations at different scales. Another characteristic is that they are usually covered by international organizations and also generate a significant inflow of capital inflows such as humanitarian aid and investment projects for reconstruction. When it comes to data collection, these disasters are usually the only ones that appear in the open international databases of disasters (e.g., EM-DAT). Their analysis is vital because, as will be seen in the following sections, they were disasters that radically modified the development patterns of Guatemala's population.

4.1.1.1. **1976 Earthquake**

The 1976 earthquake is the most massive disaster triggered by a natural hazard that the country has experienced in the last hundred years. The earthquake claimed more than 22,700 lives and injured more than 76,000 people [14,101]. The earthquake particularly had a major impact on populations living in conditions of poverty and extreme poverty [16,18].

The database built for this study was used to explore the impacts of the event on homelessness. This was estimated by computing the following for each department:

$$R_{EQ76,i} = \frac{P_{1976,i}^{[homeless]}}{P_{1973,i}} \tag{1}$$

Where: $R_{EQ76,i}$ is the (estimated) fraction of homeless population due to the impact of the 1976 earthquake in department i, $P_{1976,i}^{[homeless]}$ is the number of people left homeless due to the 1976 event in department i (data was extracted from Marroquin et. al., [14]), and $P_{1973,i}$ is the population of department i estimated in the 1973 census. The result is shown in Figure 4-1.

The analysis shows that Chimaltenango (CHM) and El Progreso (EPG) populations had (estimated) homelessness rates of 93% and 80%, respectively, due to the specific impact of the earthquake. Based on equation (1), the departments of Sacatepequez (SAC) and Zacapa (ZCP) also had a substantial majority of populations designated as homeless (<75%). Other departments such as Guatemala (Metropolitan Area); GTM, Baja Verapaz (BVZ), Sololá (SOL), Jalapa (JAL) had greater than 50% of the populations designated as homeless.

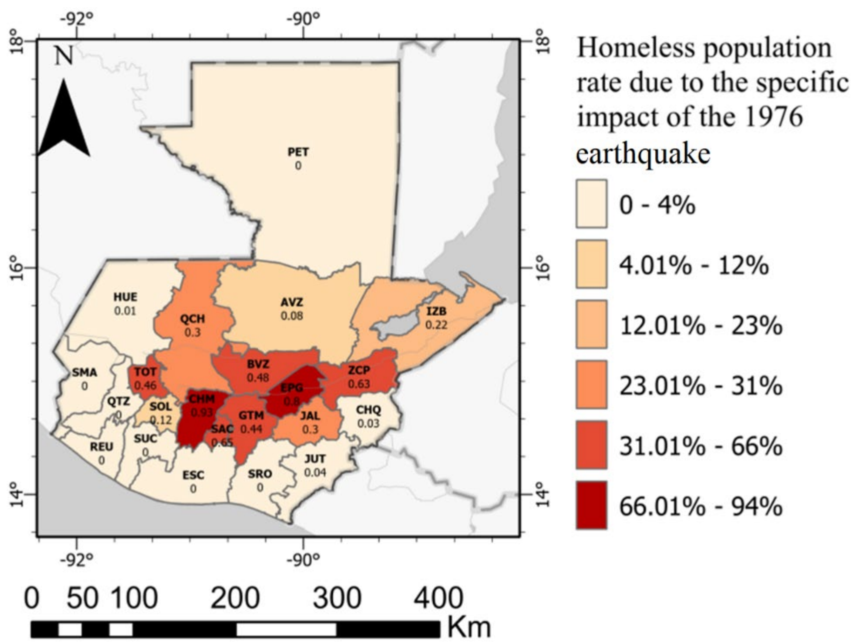

Figure 4-1: Homeless population due to the impact of the 1976 earthquake normalized according to the departmental population of the 1973 census. [14]

4.1.1.2. **Hurricane Mitch**

Hurricane Mitch in 1999 is listed as the deadliest hurricane in the western hemisphere since "The Great Hurricane" of 1780 [4]. Its passage through Honduras, Nicaragua, El Salvador, and Guatemala left severe damage to the country's population and economy. The passage of the hurricane through Central America left more than 11,000 fatalities and up to 18,000 missing persons. The most considerable damage was suffered by Honduras, where Mitch left more than 1.5 million displaced and homeless, and more than 6,500 died [102]. In Guatemala, the hurricane directly affected more than 1 million people, killing more than 260 people [103,104]. Hurricane Mitch also damaged more than 19,470 homes and destroyed more than 2,254. Figure 4-2: Affected population after Hurricane Mitch (1998) normalized by Department Population from 1994 Census. shows the spatial distribution on a departmental scale of the ratios of the population affected[1] by the disaster; i.e.,:

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[1] The authors of the Desinventar dataset define “people affected” as the number of people who suffer indirect or secondary effects, such as deficiencies in the provision of public services, businesses, jobs, in addition to the struggles related to physical and mental health. [12]

$$R_{HurrMitch,i} = \frac{P_{HurrMitch,i}^{[affected]}}{P_{1994,i}} \tag{2}$$

Where: $R_{HurrMitch,i}$ is the (estimated) fraction of population affected by the hurricane Mitch (1998) in department i, $P_{HurrMitch,i}^{[affected]}$ is the number of people left homeless after the Hurricane Mitch in department i (data extracted from Desinventar disaster dataset), and $P_{1994,i}$ is the population of department i estimated in the 1994 census.

Figure 4-2: Affected population after Hurricane Mitch (1998) normalized by Department Population from 1994 Census. shows that Izabal (IZB) was the department that had the highest ratio of the affected population (more than 95%). Other departments that followed IZB were ZCP and Escuintla (ESC) with more than 50% of the population affected and then Alta Verapaz (AVZ), EPG, Jutiapa (JUT), and Petén (PET) with a ratio higher than 25%. It is observed that departments like ZCP and Chiquimula (CHQ) repeat the protagonism of a massive disaster scenario, such as that experienced with the 1976 earthquake. Despite having a low ratio of the affected population (less than 2%), the department of Guatemala registered a higher number of fatalities (78) due to the precarious housing conditions in high-risk areas for landslides [104]. These conditions were mainly caused by the massive displacement caused by the 1976 earthquake and the armed conflict of more than 36 years (1954-1996) [14,25,98,105].

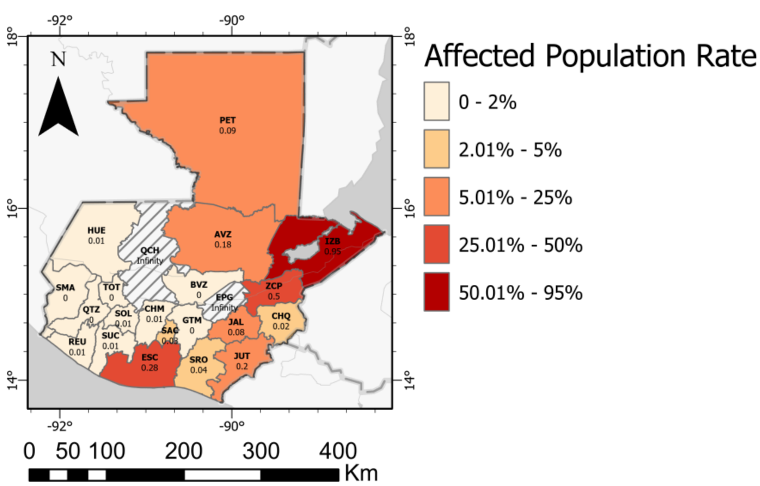

Figure 4-2: Affected population after Hurricane Mitch (1998) normalized by Department Population from 1994 Census.

4.1.1.3. **Population growth before and after major disasters**

Figure 4-3 shows the rates of population change for each census period encompassing a major disaster. The change in population time elapsed between one census and another based on a straight line growth rate computed as:

$$R_{pop\_growth,i} = \frac{P_{posterior,i}^{[total\,population]} - P_{prior,i}^{[total\,population]}}{P_{prior,i}^{[total\,population]}} \quad (3)$$

Where: $R_{pop\_growth,i}$ is the fraction (percentage) of population growth in the period between two population censuses in which the impact of a major disaster in the department i is framed. $P_{prior,i}^{[total\,population]}$ is the number of total population based on the census taken prior to the impact of a specific disaster in department i. $P_{posterior,i}^{[total\,population]}$ is the total population posterior to a specific disaster in department i. Six different census periods were analyzed: 1950-1964, 1964-1973, 1973-1981, 1981-1994, 1994-2002, and 2002-2018

One of the most notable findings was that the census period between 1973 and 1981, the period in which the 1976 earthquake occurred, recorded the lowest rate of population growth since 1950. Except for the department of Petén, which shows greater growth than in some other periods, the rest of the departments have a similar or lower growth than the pre-earthquake census periods (i.e., 1950 to 1964, 1964 to 1973) and later periods (i.e., 1981 to 1994; 1994 to 2002, and from 2002 to 2018). Further, for the intercensal period from 1973 to 1981, none of the departments that suffered the greatest damage (i.e., GTM, SAC, CHM, EPG) had a population growth of more than 20%. This finding is relevant because it suggests that a disaster that destroyed houses massively, and that left thousands of people homeless, may also have severe impacts on the dynamics of population growth. This insight could have a significance about the capacities of absorption and adaptation to the impact of disasters by the different departments' populations. At the same time, perhaps it might also contribute to glimpse potential explanations of inter-departmental migratory patterns, although a more in-depth study of the subject would be necessary.

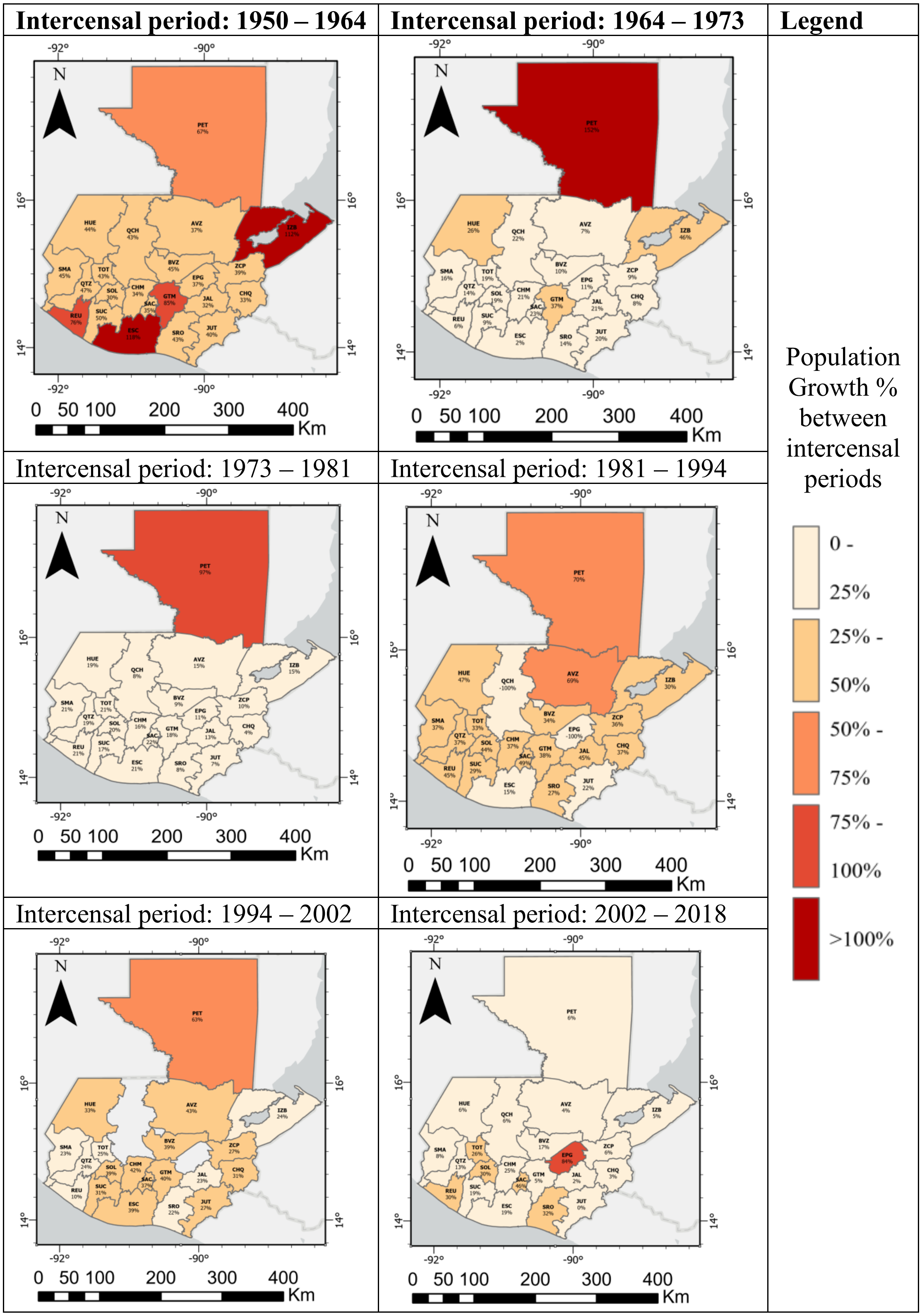

Figure 4-3: Population rate of growth by department between population censuses from 1950, 1964, 1973, 1981, 1994, 2002, and 2018.

4.1.2. **"Minor" disasters (1988-2015)**

Figure 4-4 shows the annual number of fatalities in Guatemala from natural hazards, based on data from the DesInventar database. It is observed that, except for 2007, every year between 1988 to 2015, there were more than 50 deaths due to the impact of disasters. In the period between 1988 and 2015, five peaks stand out. The highest of them was 2005, where the passage of the Hurricane Stan (i.e., flash flooding, volcanic lahars, landslides) [106,107] caused multiple concatenated disasters that left more than 500 fatalities in the country. Similarly, 1998 was ranked second due to Hurricane Mitch.

The third peak in 2015 represents fatalities (more than 300) due to the landslide of El Cambray II, Santa Catarina Pinula (in the Metropolitan Area of Guatemala). It was surprising to find so little research related to the El Cambray II landslide. A quick search on The Web of Science portal generated zero research results containing "Landslide AND El Cambray" in the title", and only two local scientific articles related to the disaster were found [108,109]. The latter perhaps could be explained by the disaster's occurrence in the absence of a natural hazard; that is, the threat was found in the conditions of vulnerability inherent in urban housing precariousness but not directly triggered by an event such as an earthquake or hurricane

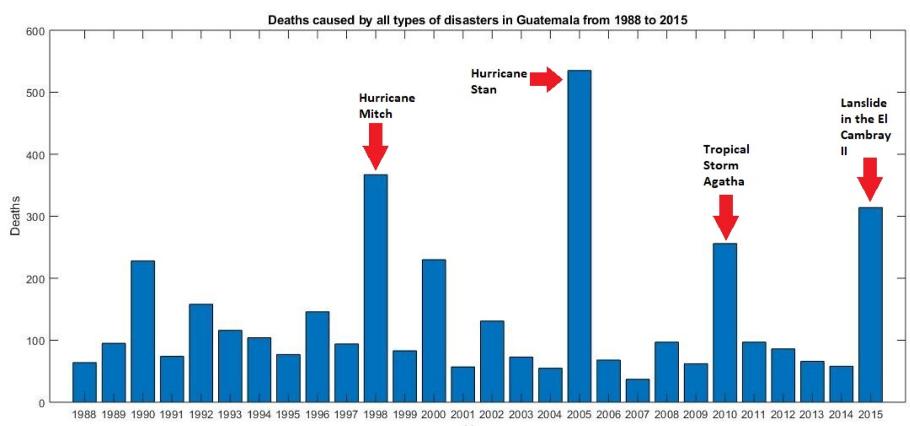

Figure 4-4: Fatalities due to disasters triggered by natural hazards and human activity between 1988 and 2015.

Spatial information tools are essential to identify the locations where more people are affected by different types of disasters. For this study, the five natural hazards with the highest occurrence in the Guatemalan territory were analyzed. The information was obtained from the DesInventar database that contains disaster data for the period from 1988 to 2015.

4.1.2.1. Earthquakes

Figure 4-5: Number of people affected by earthquakes from 1988 to 2015 by department. shows the departments where more people were affected by seismic events from 1988 to 2015. An essential finding of this figure (Figure 4-5: Number of people affected by earthquakes from 1988 to 2015 by department.) is seen by contrasting it with the map of the impact of the disaster caused by the 1976 earthquake (Figure 4-1). The 1976 earthquake had a more significant impact in the central and eastern areas of Guatemala; however, for the period from 1988 to 2015, the areas with the largest earthquake-affected population are located in the west. The latter is due to the San Marcos (SMA) department earthquakes of years 2012 (M7.4) [110] and 2014 (M6.9) [111–113]. Figure 4-5 shows these earthquakes produced relatively low mortalities compared to the 1976 earthquake. The most affected departments of the period analyzed were SMA and Quetzaltenango (QTZ), followed by Huehuetenango (HUE). It is also interesting that the DesInventar database does not contain data for the populations of ZCP, EPG, SAC, and BVZ. It is striking because the first three departments mentioned had the most significant impacts during the 1976 earthquake. However, they do not have data available for any seismic events during the almost forty years that followed.

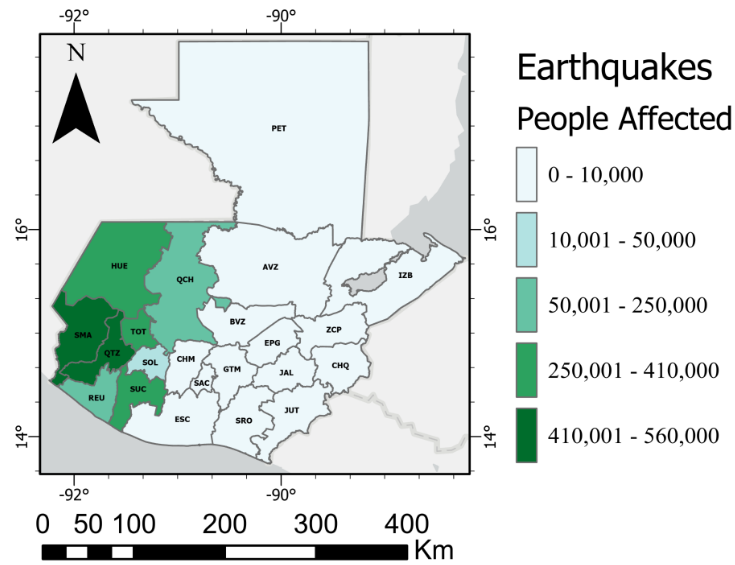

Figure 4-5: Number of people affected by earthquakes from 1988 to 2015 by department.

4.1.2.2. **Floods**

The author of DesInventar defined and classified flood as "water that overflows river-bed levels and runs slowly or quickly on small areas or vast regions"[1] [115]. Figure 4-6 shows the number of people that were affected by flood event in each department for the period from 1988 to 2015.

[1] The Desinventar definition of a flood can be more related to the riverine flood. A more broad definition of a flood is the one proposed by the National Oceanic and Atmospheric Administration (NOAA) from the US Departmen of Commerce: "an overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch." [114]

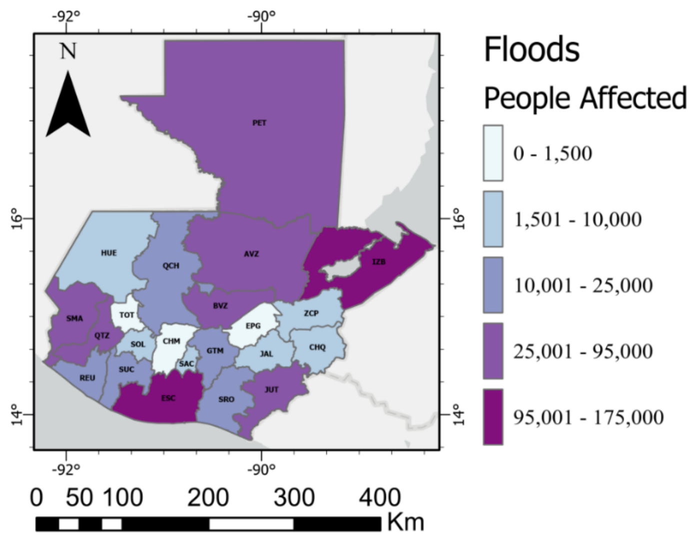

Figure 4-6: Number of people affected by floods from 1988 to 2015 in departments.

The departments that had a higher affected population due to flooding are ESC and IZB. It is noteworthy that neither of these two departments was severely affected by earthquakes in 1976, nor were they in the period from 1988 to 2015. The departments of SMA, SRO, BVZ, AVZ, and PET were also (though not as substantially) affected by floods. It is surprising to see how the department of San Marcos was the department most affected by earthquakes, but it is also among the most affected by flooding. There is a clear intersection between this map and that of the affected people by Hurricane Mitch (Fig 4.2).

4.1.2.3. **Extreme rain**

Extreme rain is defined by the authors of DesInventar as unusual rain periods that exceed the rainfall averages of specific locations or regions. Figure 4-7: Number of people affected by extreme rainfrom 1988 to 2015 in departments. shows the total number of people that were affected by extreme rain events from 1988 to 2015 in each department.

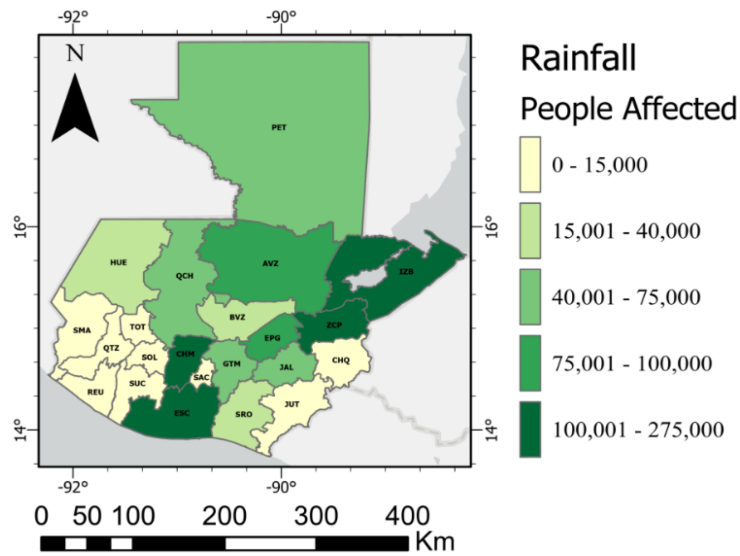

Figure 4-7: Number of people affected by extreme rainfrom 1988 to 2015 in departments.

Additionally, see Figure 4-8 shows a scatter plot was generated to determine if there was a correlation between the populations affected by extreme rain events and the populations affected by flood events for the 22 departments of Guatemala. Figure 4-7 shows that Izabal, located along the Atlantic coast and Caribbean Sea, is the department that had the highest population affected by extreme rain events. Zacapa, Chiquimula, Escuintla and Chimaltenango also registered a high affected population for the period of analysis.

On the other hand, Figure 4-8 shows that Izabal and Escuintla, both located in the far corner to the right of the scatter plot, in addition to being affected by extreme rains, were also the departments that were most affected by floods. However, the scatter plot also indicates that the pattern does not necessarily repeat for all departments. For example, ZCP and CHM were the second and fourth departments with the most population affected by extreme rains, respectively. However, ZCP and CHM were not the most affected by flood events, as evidenced by their fourteenth and twentieth positions, respectively. This could potentially indicate that the population of some departments like Zacapa are not located in areas vulnerable to floods; however, the siting of houses could cause Zacapa to be profoundly affected by extreme rains. It should be remembered that Zacapa is one of the departments most affected by the 1976 earthquake. The author of this study proposed that further study of how other types of disasters that are concatenated to extreme rain events could affect the departments in diverse ways due to the geographical and infrastructural characteristics of each territory.

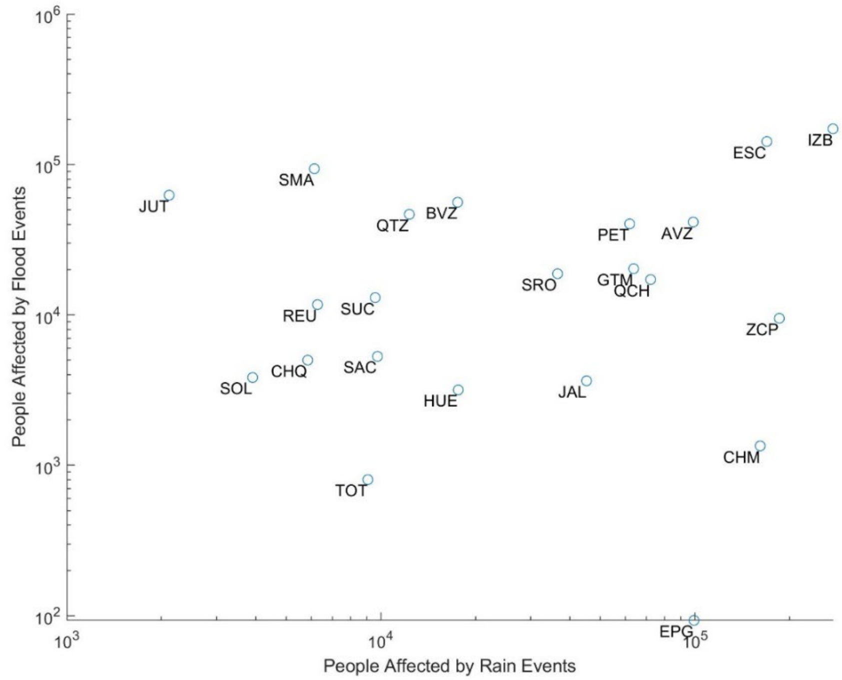

Figure 4-8: Scatter plot show the number of people affected by rain events and number people affected by flood events for the twenty-two departments of Guatemala.

4.1.2.4. Flash flooding

The authors of DesInventar define flash flooding as "torrential freshet, violent water flow in a watershed, overflowing or as torrent. Flash-floods usually carry tree trunks and/or abundant fine to bulky sediment." [115] Figure 4-9 shows the departments where more people were affected by flash flooding events for the period of 1988 to 2015.

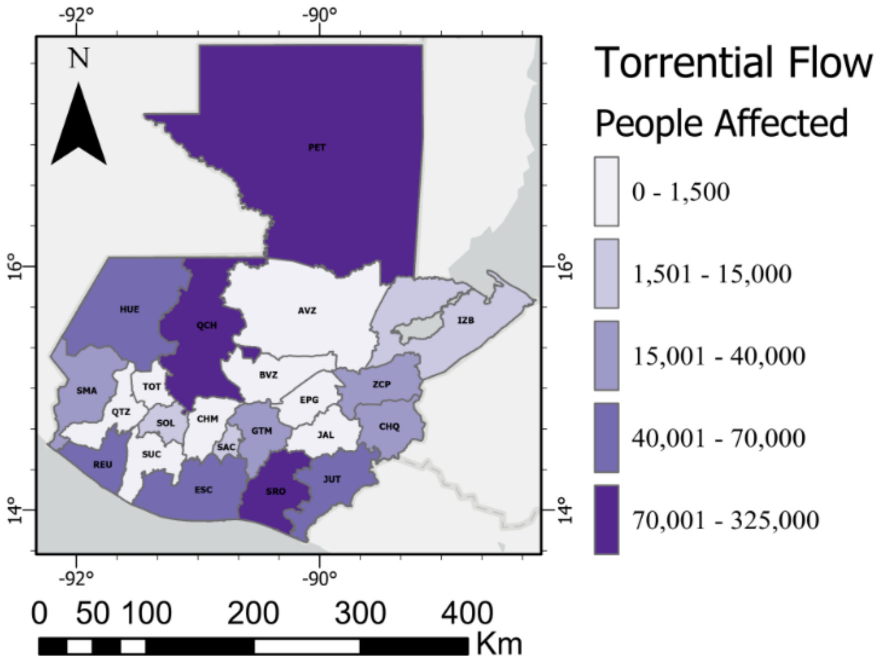

Figure 4-9: Number of people affected by flash flooding from 1988 to 2015 in departments.

In this category, the departments of PET, Quiché (QCH) and SRO had the highest number of affected populations from 1988 to 2015. The populations of these departments were not among the most affected by events of seismic or meteorological origin previously analyzed. The latter is an indication of the wide and diverse distribution of natural hazards that occur in Guatemala and a further indication of how complex risk and vulnerability reduction activities can be in the country.

4.1.2.5. **Landslides**

Figure 4-10 shows the number of people that were affected by landslide events for the period from 1988 to 2015.

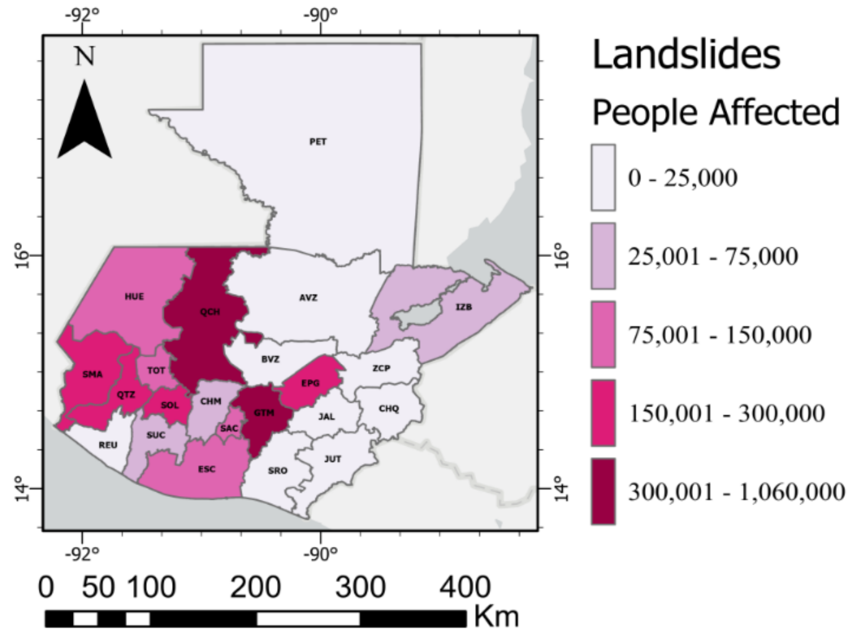

Figure 4-10: Number of people affected by landslides from 1988 to 2015 in departments.

The department with the most significant population affected by landslides in the period 1988-2015 was the Department of Guatemala. It is the first time that the department of Guatemala appears with the highest affected population for a specific hazard group. The precariousness of housing in the largest metropolitan area of the country made an enormous contribution to the number of the affected population [28,57,61–63]. The departments of Quiché, San Marcos, Sololá, and El Progreso also have notable population counts affected by landslides. For Quiché, an interesting intersection between the maps of affected population due to landslides and flash flooding is observed, potentially indicating effects from unstable slopes, though an event specific (time-series) analysis would be necessary to determine whether this relationship exists. In the cases of Sololá and El Progreso, data on the population affected by landslides could suggest the hypothesis that this problem is an extension of the severe housing crisis caused by the 1976 earthquake [14]; however, specific historiographic studies and spatial analyzes of the dwelling in these departments would be necessary to confirm this hypothesis.

4.2. Disasters impact on housing structures

The results of the analyses carried out with the data collected and compiled from the housing censuses for the period from 1973 to 2018 indicate a notable change in certain aspects of materials in Guatemalan homes. The analysis of this period focused mainly on housing materials in use before and after significant disasters; specifically, the 1976 earthquake, Hurricanes Mitch and Stan, and Tropical Storm Agatha. The analysis was segmented for the four intercensal periods (the time elapsed between two censuses). In this way, the disaster's potential impact on the population's housing stock can be observed at various short, medium, or long-term time scales.

Section A.1 of Appendix A includes a compilation of figures showing the evolution of materials used in homes, by department. The left panel of each figure shows the absolute number of homes using each housing material while the right panel shows the fraction of homes using the material. The top row of each figure provides information related to roof types, the middle row provides information related to wall types and the bottom row provides information related to occupancy conditions. The subsections that following focus on a more aggregated analysis.

4.2.1. Housing roof materials

Figure 4-11 shows the percent of use for eight different roof types categories (concrete, sheet metal, cement/asbestos, tile, thatched, waste material, other, and ignored) for the housing census years from 1973 to 2018. The top figure shows percentages across all departments while the bottom figure shows the same information, excluding the department of Guatemala. Some categories of roofing materials such as thatched (straw, palm), tile, and other declined markedly over the five census periods shown. In contrast, metal sheet roofing was the material with the highest increase, some departments doubled or tripled the number of homes with such roofs. Concrete roofs across increases as a percentage of all roof types; however, comparing the top and bottom plots of Figure 4-11 shows that the increase is driven predominately by an increase in concrete roofs in the department of Guatemala (GTM).

To further explore how roofing material use has changed across departments, Figure 4-12 and Figure 4-13 shows the percentage of dwellings with sheet metal roofing and concrete roofs, respectively, by department for the 1973 and 1981 censuses (the censuses taken before and after the 1976 earthquake). Figure 4-14 shows similar information but for sheet metal roofs, comparing the censuses from before and after Hurricane Mitch.

Figure 4-12 is divided in three sub-plots: (a) the top bar plot shows both 1973 and 1981 sheet metal roofing percentages relative to all roofing types; (b) the middle plot shows the sheet metal roofing percent points change from 1973 and 1981 in relation to all the roofing categories; and (c) the lower plot shows the percent change difference of sheet metal roofing between 1973 and 1981.There is notable variability across departments with regard to a transition to sheet metal roofing during the noted time period. The increase in the percentage of dwellings with sheet metal roofs is largest in CHM, SOL, EPG, SAC, and ZCP. With the exception of SOL, these also happened to be the departments most affected by the 1976 earthquake based on homeless population from the events (see Figure 4-1): CHM (93%), EPG (80%), ZCP (63%), and SAC (65%). GTM also had a sizeable percentage of the population rendered homework by the 1976 earthquake (44%) is associated with the smallest change in roof types. However, as observed in Figure 4-13, GTM had a substantial increase in the percentage of concrete roofs during the same time period.

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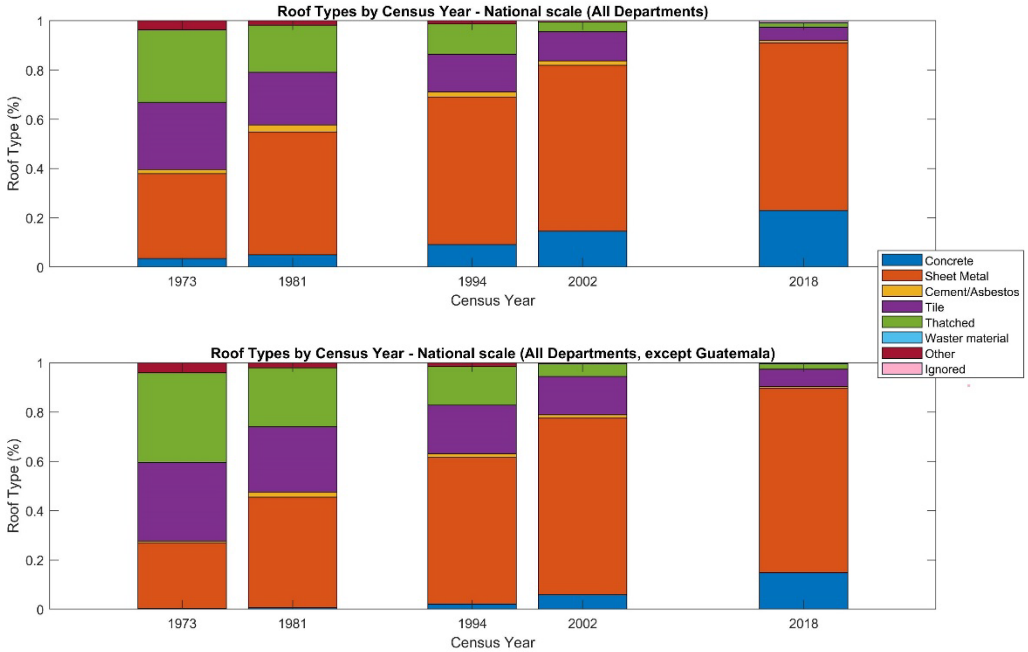

Figure 4-11: Roof type percentages for the housing census of 1973, 1981, 1994, 2002, and 2018

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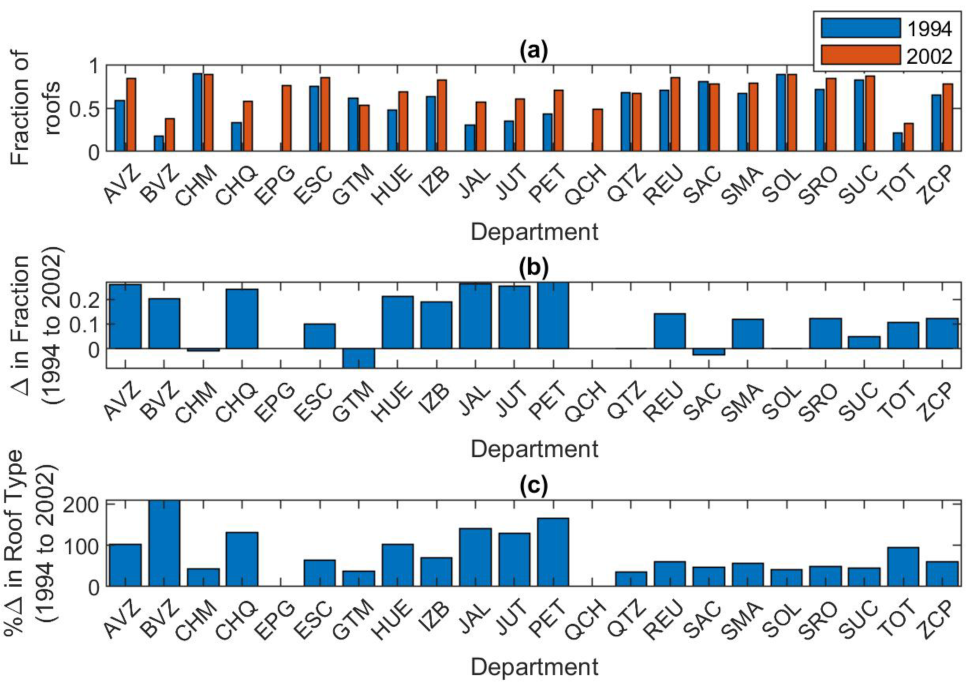


Figure 4-12: Sheet metal roofing rate increase from 1973 to 1981 by Department

Figure 4-13 shows the percentage of dwellings with concrete roofing by department for the 1973 and 1981 censuses. Figure 4-13 is divided in three different sub-plots: (a) the top bar plot shows both 1973 and 1981 concrete roofing percentage in relationship to all the different roofing types; (b) the middle plot shows the concrete roofing percent points change from 1973 and 1981 in relationship to all the roofing categories; and (c) the lower plot shows the percent change difference of concrete roofing between 1973 and 1981. It is evident that, compared to sheet metal roofs, the percentage of houses with a concrete roof was considerably lower for most of the departments before and after the 1976 Earthquake. While the overall fraction of houses with concrete roofs remained low in most departments, Figure 4-13 shows a considerable (relative) increase in the implementation of concrete roofing , with a percentage change difference of more than 200% between 1973 and 1981. The key exception is GTM, which showed a notable increase during the target period. In other departments, there was not any relationship noted regarding the relative increase in concrete roof types for those departments most affected by the 1976 earthquake. Most of the roofing materials were sheet metal or of natural origin and were obtained in a rudimentary way, such as palm, straw; and they were processed in an artisan way, such as thatched roofing and tiles.

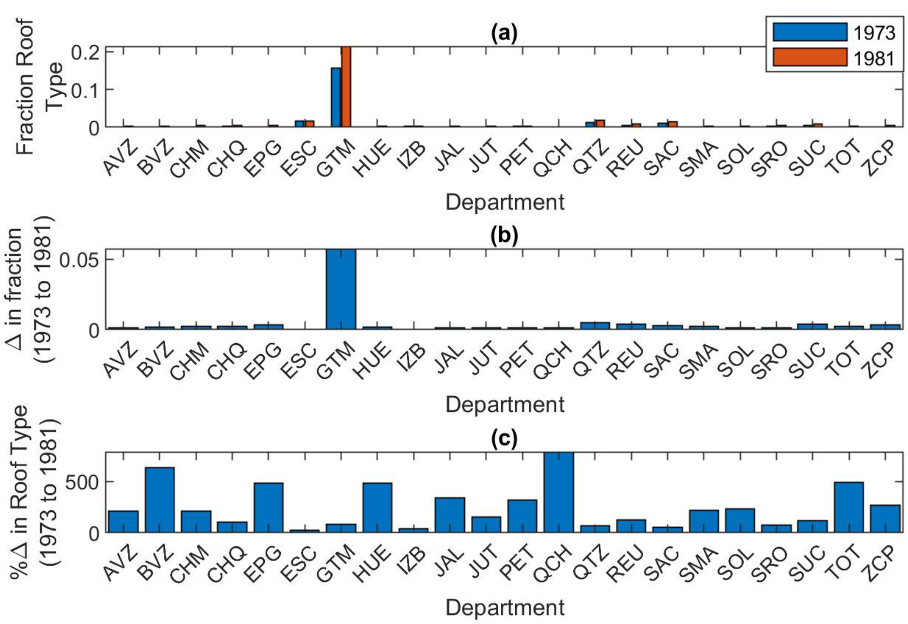


Figure 4-13: Concrete roofing rate increase from 1973 to 1981 by Department

Figure 4-14 shows the change in sheet metal roofing from 1994 to 2002 (the censuses before and after Hurricane Mitch). Like the earlier plots, Figure 4-14 is divided in three different sub-plots: (a) the top bar plot shows both 1994 and 2002 sheet metal roofing percentage in relationship to all the different roofing types; (b) the middle plot shows the sheet metal roofing percentage point change from 1994 and 2002 in relationship to all the roofing categories; and (c) the lower plot shows the sheet metal roofing percentage change between 1994 and 2002. For this particular period, the pattern of increase in metal roofing and decrease of ceilings of natural or artisan origin were repeated over all (see Figure 4-11). However, unlike observations associated with the time period around the 1976 earthquake, there was not a noticable relationship between the departments with the largest increases in percent of dwellings with sheet metal roofs and those with notable impacts from Hurricane Mitch.

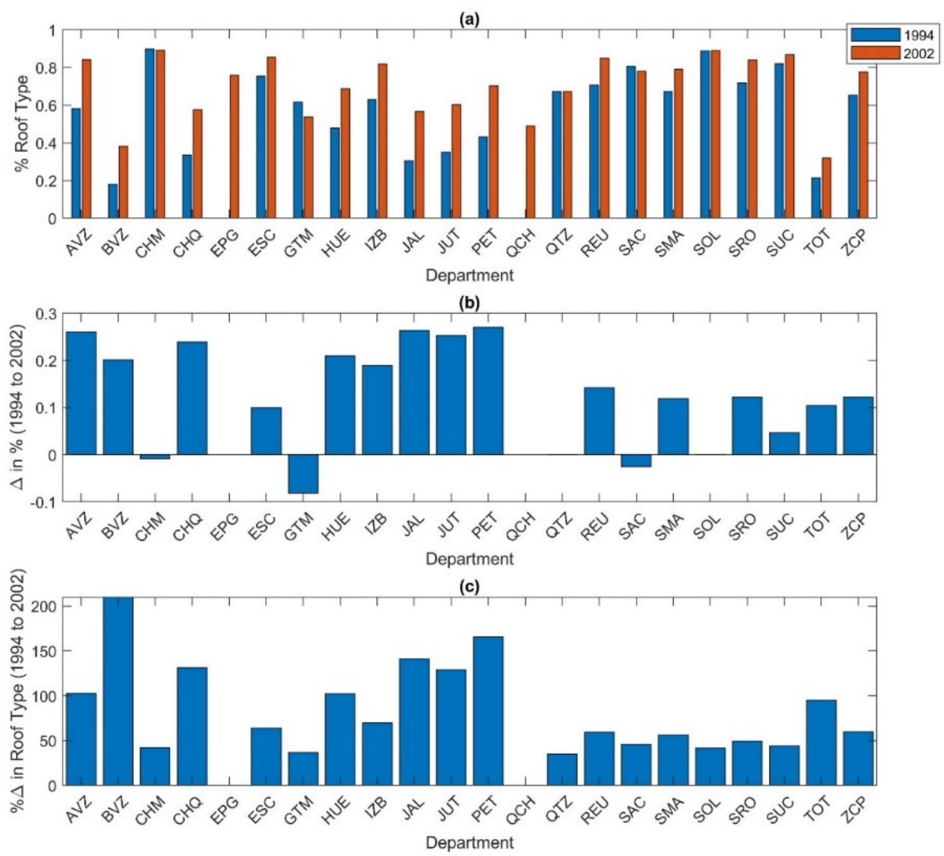


Figure 4-14: Sheet metal roofing rate increase from 1994 to 2002 by Department

The intercensal periods from 1981 to 1994, and from 2002 to 2018, show very similar changes in roofing materials, with an increase in manufactured materials (concrete and sheet metal) and a reduction in more natural materials. These transformations began to be more and more noticeable not only in the capital of the country but also in the rest of the departments, as shown in the lower graph of Figure 4-11.The former period (1981-1994) could have been influenced by its proximity to the 1976 earthquake, where changes in housing materials and the construction of new houses could continue to have a considerable impact on the transformation of housing in Guatemala. However, insufficient information is available to parse out the effects of the earthquake relative to more general, long-term trends. The latter period (1994-2002) continues with patterns of changes in roofing materials similar to those of the previous period; that is, increase of sheet metal and concrete roof, and decrease of thatched roofs, tiles and other materials. Based on available information, it was not possible to parse whether changes in roofing materials were influenced by the impact of Hurricane Mitch.

4.2.2. **Housing wall materials**

Figure 4-15 shows the changes in the wall type percentage throughout the five different housing censuses (1973, 1981, 1994, 2002, and 2018). The upper figure shows the percentage, including the twenty-two departments of the country. The lower figure shows the percentage, including all the departments except the department of Guatemala, where the country's capital and the metropolitan area are located. Concrete has increased substantially, while adobe and other natural materials (e.g., Bajareque, Tree Bark, or Wood and Cane Sticks) have seen a reduction in usage. Wood usage has remained somewhat steady over time.

The wall building materials that suffered the most significant increase after massive impacts such as the 1976 earthquake and Hurricane Mitch were lumber wood, metal sheet, waste material, and others [26,34].

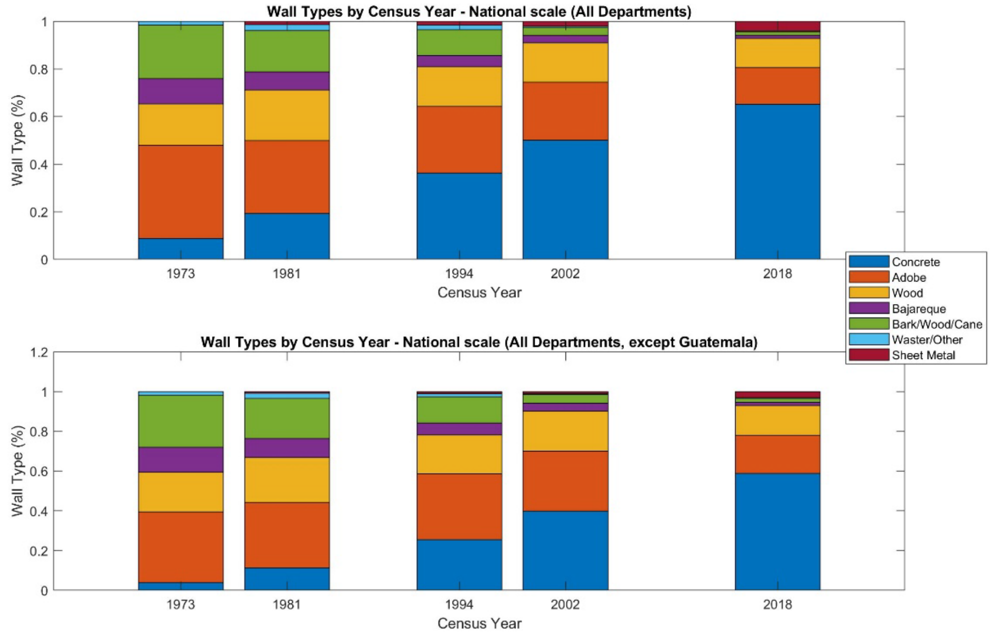


Figure 4-15: Wall type percentages for the housing census of 1973, 1981, 1994, 2002, and 2018

To explore the potential effects of the 1976 earthquake on building wall materials, Figure 4-16 shows percentages of wall type use over the five census periods for the departments most affected (top), moderately affected (middle), and least affected (bottom) by the 1976 earthquake. For the departments least affected by the earthquake, there is a somewhat monotonic trend observed with a steady increase in concrete walls, a slight decrease in adobe walls, a notable decrease in natural materials, and steady use of wood. However, for the departments most affected by the earthquake, there is a notable decrease in adobe walls during the period encompassing the 1975 earthquake. In parallel there is a notable increase in wood. Use of natural materials does not decrease as quickly over time in the departments most affected by the earthquake as observed for those least affected. For the departments moderately affected by the earthquake, there is a decrease in use of adobe and a notable increase in concrete and (to a lesser extent) wood. Natural materials saw a much quicker reduction in usage relative to the other groups.

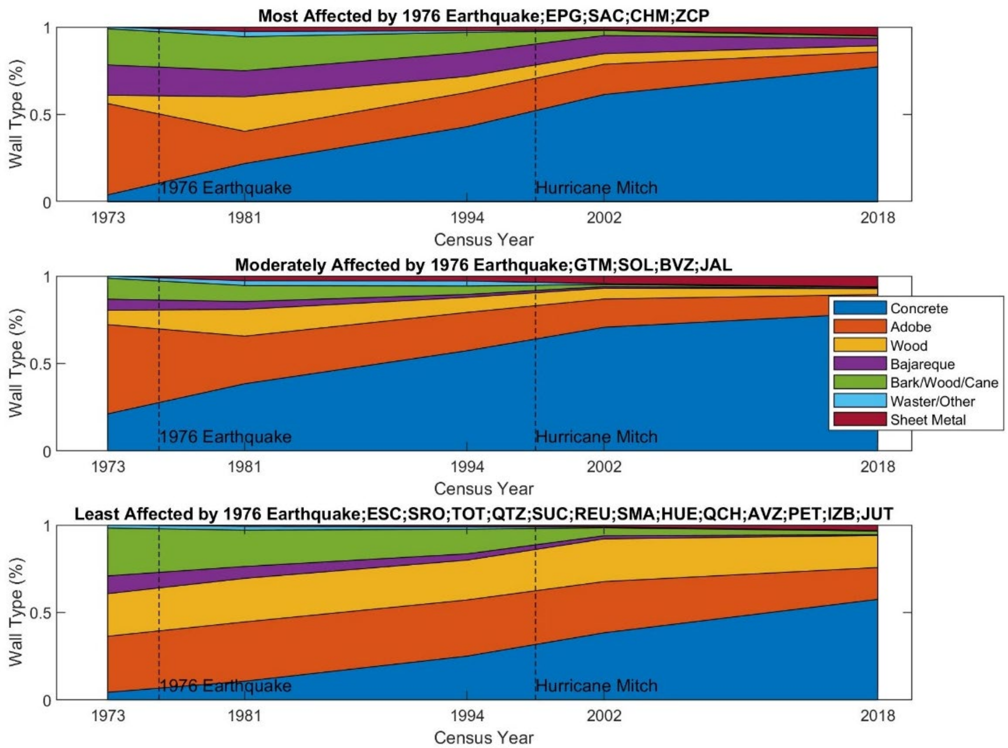


Figure 4-16: Percentages of wall type classified for the departments most affected (top), moderately affected (middle) and least affected (bottom) by the 1976 earthquake.

While these patterns do not imply causality they offer potential insights that can inform future research efforts. For example, the described patterns could have clues about the population's capacities to adapt to new conditions after the impact of a disaster, including changing preferences for certain building materials or limitations related to material availability. Additionally, it might also have implications for the analysis of emergency aid policies implemented during major disasters. For example, providing insights about the characteristics and quality of the emergency housing provided and its durability.

4.3. Disasters impact on housing utilities

Household connections to services or utilities are inherently linked to modern public and private infrastructure networks (e.g., water, electricity, and sanitation services). Households' ability to connect to these services depends on economic, social, historical, and cultural factors. Connections to these infrastructure networks improve households' quality of life by generating an alternative that potentially enhances their well-being, as a recent study in Guatemalan infrastructure showed [117]. However, these networks could also increase potential for impacts from infrastructure failures during natural hazard events. The results of this subsection serve as a first “stepping stone” to inform future research efforts to explore, in greater depth, the resilience capacities of Guatemala's infrastructure systems. That is, in exploring the absorptive (absorbing impacts of disruptions with little effort), adaptive (adjusting to unfortunate situations by making changes), and restorative capacities (the speed to return to a normal or improved system) that together make up the resilience paradigm [118].

To understand the impact of disasters on housing utilities, the period of 1994 - 2018 was analyzed (except for drinking water supply, where it was also possible to add the information from the 1981 census). Due to limitations inherent in the population and housing censuses, it was not possible to collect and compile information related to utilities from censuses prior to 1994 (with the exception of drinking water). The period analyzed in this section contains significant disasters such as Hurricanes Mitch (1998) and Stan (2005), Tropical Storm Agatha (2010), Tropical Depression Twelve-E (2011) and the San Marcos earthquakes (2012 and 2014); however, it does not include the 1976 earthquake. These disasters may have had an impact on the population's access to resources.

Some of the utilities analyzed were: type of drinking water supply, source of energy for cooking, type of lighting source, type of toilet, and methods for garbage disposal. Overall, the initial statistical exploration results do not show a specific change related to the impact of a particular disaster.

Figure 4-17: Housing utilities and services, and type of dwelling for different periods per million households for Guatemala (at the national level) provides information related to housing utilities, services, and dwelling types at a national level (Appendix

A.2 provides the same type of information at a departmental level); specifically it illustrates:

- Households source of energy for cooking in terms of the absolute number of households in Guatemala (top row, left).
- Households type of drinking water supply in terms of the absolute number of households in Guatemala (top row, right).
- Households type of lighting source in terms of the absolute number of dwellings in Guatemala (middle row, left).
- Households type of toilet in terms of the absolute number of dwellings in Guatemala (middle row, right).
- Households methods of garbage disposal in terms of the absolute number of dwellings in Guatemala (low row, left).
- Households type of dwelling of the absolute number of dwellings in the Guatemala (low row, right).

Household source of energy for cooking includes: Propane gas, Firewood (leña in Spanish), Electricity, Charcoal, Kerosene, Household doesn't cook and other. Type of drinking water supply includes: Pipeline (for one house), Pipeline (for more than two houses), Public tap, Well, Rainwater, River or Lake, Spring, Potable water delivery and other. Households Type of Lighting Source includes: Electrical network, Kerosene, Candel, Other, Solar panel or wind power. Type of Toilet includes: Toilet (connected to a drainage network), Toilet (connected to a septic tank), Bucket toilet, Pit latrine or cesspit, and does not have a toilet. Households Main Method of Garbage Disposal includes: Municipal collection, Private collection, Burning it, Burying it, Littering in water bodies, Littering on land, Compost/Recycle, Other. Type of dwelling includes: House, Apartment, Subletting room in a house, Rancho, Slum dwelling / improvised, Other, and Ignored.

The analysis of drinking water supply shows a constant increase in access to pipelines since 1981. There is also a noticeable decrease in more rudimentary forms of water supply, such as obtaining water directly in rivers and lakes. An interesting change reflected in most departments is the increase in shared pipeline connections; this happens when two or more houses share a single connection to the network. The preceding observation is accentuated in all departments in the intercensal period from 2002 to 2018.

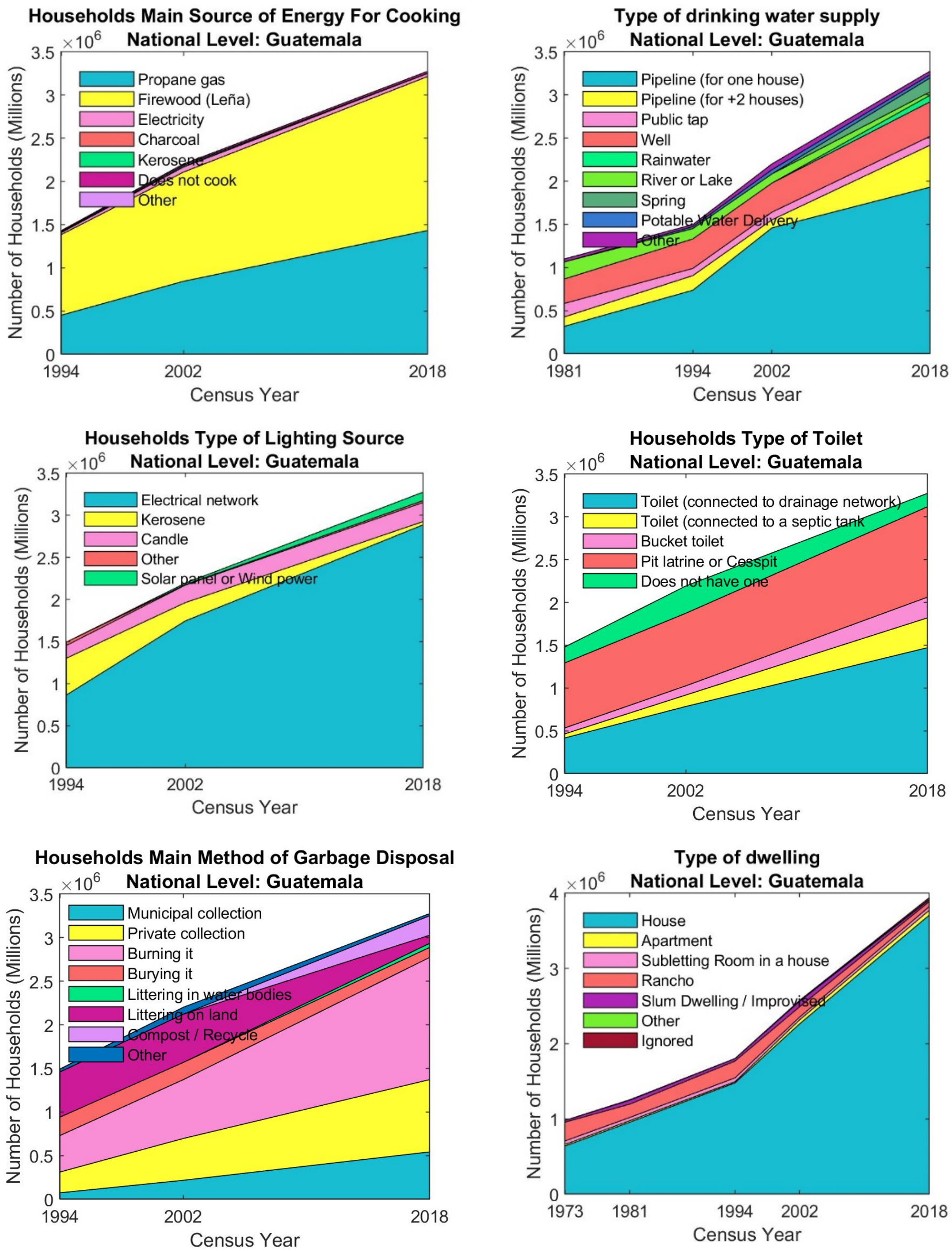


Figure 4-17: Housing utilities and services, and type of dwelling for different periods per million households for Guatemala (at the national level)

Regarding the sources of energy for cooking, two dominant sources are observed: firewood and propane gas. In general, the distribution of the two types of energy has not varied considerably since 1994. Other variables in this analysis were charcoal, electricity, kerosene, other, and population that does not cook, although neither of them had significant changes in the period analyzed.

Analysis of the type of lighting source shows a significant increase in connectivity to the electrical network and a decrease in the use of light fuels such as kerosene. It is also observed that the use of candles has not had representative changes since 1994, yet remains the light source for a non-negible fraction of households. Finally, a slight increase is observed in some solar and wind power departments.

The analysis of the graphs of methods of garbage disposal shows globally a decrease of households that throw their garbage on land, rivers, lakes, and an increase in the methods of private and municipal garbage or collection, and households that burn their garbage. The most notable growth is reflected in private collection services; this change was reflected during the period from 1994 to 2002 and remains constant until 2018.

Chapter 5. Discussion

One of the main challenges in Guatemala is the lack of understanding of the magnitude of the complexities of reducing disaster risk in Guatemala, in addition to the general lack of understanding of how disasters are strongly linked to the human development of populations. Disasters are traditionally seen as cataclysms that temporarily interrupt life. However, it is not observed how they contribute to recreating other disasters that are continuous, permanent, and probably just as deadly as those that occur due to the impact of a natural hazard.

An evident manifestation of our lack of understanding of cause-effect is seen in housing provision during emergency relief stages in a developing country like Guatemala. Experience often shows how multiple organizations and institutions rush to "solve" problems by providing goods and services that meet their own needs but have little to do with the needs of victims. Emergency relief organizations often measure their success in terms of the donor or sponsor and not in terms of the victim [1,9,26,119]. The prominent disaster relief specialist, Frederick C. Cuny, framed some of the problems introduced by housing programs in his 1978 report “Disasters and The Small Dwelling: The State of Art”:

> The house is seen as the end-product or result…. When the number of required houses has been built, or when the funds run out, the program ends. The agency then measures its success by the number of units that were produced, whether they were produced within a certain time limit, whether the project came in above or under budget, and what percent of the population within the assigned area has been re-housed…. Rarely has anything been left in the community other than an artifact…. The structures which have been built cannot be repaired or maintained…. The typical housing program, either relies upon skills which are non-existent within the community or introduces new skills without ensuring that the capacity to use them is left within the affected community. [26]

Additionally, organizations' results reports frequently exclude the new conditions of vulnerability that their programs generate (i.e., homes with rapid obsolescence). The linkages of the emergency relief system (i.e., cause-and-effect relationships and interactions between components) have been barely examined, making it difficult to understand the real opportunities to enhance the system. The latter is not a failure only related to housing recovery programs, but extends to all branches of post-disaster recovery systems. For instance, during the 1976 Earthquake in Guatemala, the unnecessary massive importation of food by donor agencies harmed the food and market systems of local farmers and destabilized the ways of survival of entire communities [120].

The purpose of this study was to increase the understanding to the impact of disasters in Guatemala by collecting data from past experiences of disasters, as well as of population and housing censuses, to create a sophisticated dataset through which the impact of disasters on the society and built environment could be analyzed. In addition, this work has created a unique database that can form the foundation for future studies.

5.1. Disasters impact on population

The current study found that the impact of major disasters, such as the 1976 Earthquake, could potentially have implications for demographic characteristics like population growth. For instance, the census period from 1973 to 1981 (the period during which the country was affected by a major earthquake) showed the lowest rate of population growth compared to the other periods (i.e., 1981 to 1994, 1994 to 2002, and 2002 to 2018). While this provides initial insight regarding potential relationships, future study is needed to ascertain causality.

Additionally, the analysis also reflected the consistent impact that natural hazards have in Guatemala since there are no years between 1988 and 2015 that disasters have had no impact on the lives of Guatemalans, with oscillations between 40 and almost 550 fatalities per year.

The spatial analysis at a departmental scale showed a wide distribution of disasters. Using maps of affected population, it is observed that practically all the departments of the country were affected by one or more natural threats. The spatial and temporal variability of the different occurrences of natural hazards, added to the analysis of housing roofs and walls, show that disaster risks are distributed throughout the country. These results have a potential implication on the importance of decentralizing disaster risk reduction policies to find adequate solutions to each department's conditions. Some natural hazards require actions that are implemented at the national level. For example, earthquakes have caused severe damage in all departments of the country, perhaps with the sole exception of Petén. The spatial analysis also suggests the importance of implementing actions that reduce natural threats of hydro-meteorological origin at the national level, since the risks of concatenated occurrences of this type have had devastating effects with a wide spatial distribution. In particular, the spatial analysis may also suggest the urgency of focusing solutions for certain threats in specific places, such as vulnerability to landslides in the departments of Guatemala and El Quiché.

5.2. Disasters impact on housing structures

The longitudinal analysis of the impact of disasters on housing construction materials provide preliminary insights regarding the impact that massive disasters may have on the evolution of the built environment components and, therefore, disaster resilience. The stacked time-series graphs showed that both the 1976 earthquake and Hurricane Mitch were events that could have potentially contributed to changes in the roof and wall dwelling components. An increase in industrialized origin materials such as metal roofing sheets and concrete was observed, and a decrease in natural and artisan origins such as adobe, bajareque, cane, palm. The latter does not mean that the use of these materials has disappeared; for instance, departments such as Huehuetenango, Baja Verapaz, Totonicapán, and Jalapa were not impacted by earthquakes during the analyzed period show between 40% and 60% predominance of adobe walls.

Particular emphasis is placed on the change between adobe and gutter walls to concrete walls due to the differences that each construction method entails and its implications for reducing risks of telluric and hydrometeorological origin. Adobe constructions are characterized as a simple construction technique with an inadequate response to earthquake ground shaking due to their heavy-weight, low strength, and brittle behavior [33–36]. However, no studies were found that determines the current state of reinforced concrete in Guatemala. Some studies in other developing countries have shown that low concrete quality has been one of the causes of several disasters triggered by earthquakes [37,38].

Another interesting observation was found in the departments of Chimaltenango, Sololá, and Zacapa (Appendices A.1.4, A.1.7, and A.1.19) about the immediate decrease in adobe usage as a wall housing material in the census period from 1973 to 1981 and an increase in the subsequent intercensal period (1981 to 1994). The later has implications for understanding how societies repeated methods construction that led to vulnerability to the seismic threat despite having experienced a massive disaster that caused the massive loss of housing. Additionally, the latter has implications for analyzing disaster management agencies' performance and institutions on emergency relief actions after the impact of major disasters. The temporary and short-term increase of construction materials like wood followed by another rapid decrease in usage of the same material is another interesting observation that might be related to emergency relief actions. This phenomenon was also observed in the departments of Chimaltenango, Sololá, and Zacapa (Appendixes A.1.4, A.1.7, and A.1.19). The latter observation could suggest that emergency relief institutions and organizations provided short-term solutions that possibly did not contribute to solving the disaster risk of households.

5.3. Disasters impact on housing utilities

Contrary to the observations on housing wall and roof materials evolution, there was not an indication that disasters have sparked changes in any particular type of household utility. The most critical changes in utilities during the period of 1994 - 2018 were increases in connection to the electrical network and kerosene reduction as lighting sources. A decrease was observed in the number of people who litter either inland or in water bodies. At the same time, the municipal and private garbage collection services increased, as well as the population that burns their garbage. Other types of utilities remain constant without significant changes, such as the type of toilet or primary energy for cooking. This could imply that the stagnation in the improvement of the quality of services has not contributed to increasing resilience to disasters in the last 26 years. An exception to this pattern, however, is observed in the results of the analysis of types of drinking water supply. These results showed a considerable increase that globally doubles, and in some cases triples, the rate of the population that has access to individual or shared piped water (shared with two or more houses, or public taps in the streets).

The longitudinal analysis observations suggest that disasters do not appear to have caused a representative change on the households' utilities and resources, and therefore, have not contributed to improving disaster resilience in Guatemala. This insight might contribute to extending the discussion of the disaster risk reduction field towards the widely known phrase of "disasters as opportunities for social change" [39,40]. The improvements in the quality of resources and utilities may be due to other macroeconomic phenomena and global policies of transition to fundamental human rights such as access to drinking water. However, further exploration would be needed to understand how much of these changes could be attributed to disaster risk reduction policies and actions. However, improving the quality of households' resources and utilities has implications for resilience to future disasters, and their effects should be furtherly explored.

5.4. Limitations

The three significant limitations of this study are data availability and quality of the collected data, as well as the archival methods design and its performance. First, being limited to obtaining only one open population and housing dataset (i.e., 2018 Census), this study required a massive effort to obtain the data from digital and paper sources manually. The research design might have differed if the archival research tasks had been less, probably focusing more on longitudinal and probabilistic analyzes of disaster occurrence. To the above, it should be added that the author of this thesis had no previous experience or training in archival methods, so learning was also part of the process. This limitation is a sample of the additional challenges that researchers face when researching developing countries, such as Guatemala. The experience of collecting the data was, however, enriching and formative for all the actors involved. Another limitation regarding data availability was related to the DesInventar disaster dataset only covering 1988 to 2015, which is a smaller span than the census datasets from 1973 to 2018. Therefore, it was not possible to analyze the impact of the so-called minor disasters for the intervals from 1973 to 1988 and from 2015 to 2018. Additionally, there was a low degree of data completion for the 1994 population and housing census. It was impossible to find information regarding two departments (Quiché and El Progreso); the absence of this data represents 11% of all the departments of Guatemala.

Secondly, the accuracy of the results might have been affected by human errors introduced during the archival digitization process. Detailed documentation of the collection and digitization were not carried out due to the author's lack of knowledge about the importance of this process in providing support for information accuracy. For instance, the sources and number of errors and manual corrections of the data could have been registered and measured to determine the effectiveness of the process. The latter could have generated insight regarding the reliability and replicability of the performed archival methodology. Additionally, there is an undetermined amount of error inherent to each housing and population dataset's nature. Unfortunately, it was also impossible to determine to what extent these errors could have affected this study.

Lastly, the database compiled at a sub-national departmental scale would be more explanatory if it had an urban-rural delineation that reflected two concepts of ways of life that exist in parallel in Guatemala. The way that information is represented in this study might make it difficult to differentiate and contextualize the country's reality for an audience that is not knowledgeable about Guatemala. Notwithstanding these limitations, the study suggests that the documentation of experience is crucial to understanding the critical impact of short-term disaster management performance and long-term disaster policies and programs.

5.5. Recomendations for future research

Based on the results of the study, there are several recommendations for future research. First, further research should be undertaken to explore the societal framework and demographic characteristics more deeply and understand how they interact with the impact of disasters. For instance, population data could have a sub-classification on rural and urban populations, or by gender. Population data could also be classified by ethnic groups since there is evidence of disasters impacting Mayan indigenous populations' harder [15,16,107]. A sophistication of the dataset would be required to make this type of analysis. Therefore, a similar archival method could be performed targeting specific information relevant to the research question of future studies.

Additionally, further research is needed to fully understand the implications of the programs and policies implemented during emergency relief operations and contrast them with findings of this thesis regarding the possible impact of disasters on transforming the built environment through modifying housing components characteristics. The preceding could contribute to elucidate whether the observed changes in infrastructure are due to the impact of disasters and disaster management actors; or if they were caused by other types of events not related to disasters. Research in this area could contribute to generating innovative ideas after exploring and learning from past mistakes and successes, as well as identifying current programs and policies that do not allow the development of disaster resilience in Guatemala.

Lastly, further research needs to be carried out to enhance disaster management of data and accountability of casualties during the impact of a disaster. This study evidenced discrepancies between the different databases of international and local disasters; this situation hinders immediate actions related to response and recovery to disasters, including the transparent communication of casualties information to the population. Simultaneously, it makes long-term analyzes similar to those carried out in this study difficult, not allowing critical reflections to be generated that contribute to changing the paradigm of traditional disaster management.

5.6. Conclusions

The results of this study led to three major conclusions. The first conclusion is that the intersection of historic disaster databases and housing and population data can enhance our understanding of past experiences with disasters by exploring the linkages between disaster impacts and changes in population growth, housing structure components, and household utilities resources. The second conclusion of this study is related to the widespread risk exposure to disasters in Guatemala. The 22 departments of the country are exposed in various ways to multiple natural hazards. The latter has been studied by multiple authors [1,11,29,47]; however, this study genuinely contributes to confirming the evidence by analyzing a 27-year extension of disasters (i.e., between 1988 and 2015) and empirically contrasting it with 45 years of population and housing information (i.e., between 1973 and 2018). No studies of this nature were found in the literature. The third conclusion of this study is that the 1976 Earthquake may have influenced housing wall and roofing materials in Guatemala, particularly in the departments were they hit harder, but not only limited to those regions. The significant transformations observed were the substitution of vernacular architecture (i.e., adobe, mud bricks, thatched roofs, cane, and sticks walls) by a more modern and industrialized one (i.e., metal sheet roofing, reinforced concrete). The latter has been also demonstrated by a few studies through surveying methods [14,28,34], however, as mentioned before, the long-term data analyzed in this study make it a novel and one-of-a-kind contribution. On the other hand, it was also observed that disasters did not have much impact on improving the households' access to utilities and resources.

Appendix A. Summary Housing Census Figures by Department

This Appendix provides a series of figures showing the evaluation of construction materials and utility availability by Department based on available census data. Section A.1 provides information on dwelling construction materials. Specifically, the figures contained in that section are structured with one figure per department that illustrates:

- Dwelling roof types in terms of the absolute number of dwellings in the department (top row, left) and the percentage of dwellings in the department (top row, right).
- Dwelling wall types in terms of the absolute number of dwellings in the department (middle row, left) and the percentage of dwellings in the department (middle, right).
- Dwelling occupancy condition in terms of the absolute number of dwellings in the department (low row, left) and the percentage of dwellings in the department (low row, right).

Roof types include: concrete, sheet metal, cement/asbestos, tile, thatched (straw or palm), waste material, and other. Wall types include: concrete, adobe, wood, bajareque, tree bark (wood or cane sticks), other or waste material and sheet metal. Occupancy conditions include: Occupied, unoccupied, temporary use, and does not know or no answer.

Section A.2 provides information related to utilities. Specifically, the figures contained in that section are structured with one figure per department that illustrates:

- Households source of energy for cooking in terms of the absolute number of households in the department (top row, left).
- Households type of drinking water supply in terms of the absolute number of households in the department (top row, right).
- Households type of lighting source in terms of the absolute number of dwellings in the department (middle row, left).

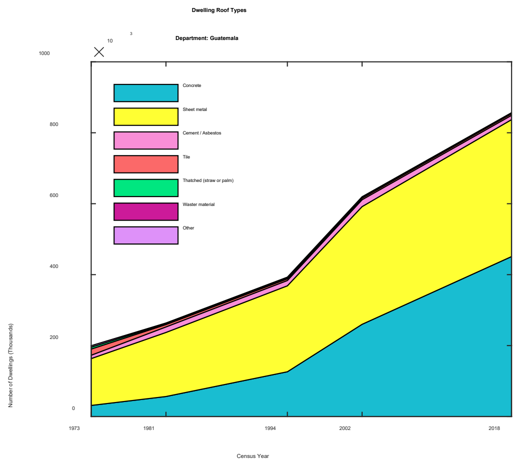
- Households type of toilet in terms of the absolute number of dwellings in the department (middle row, right).
- Households methods of garbage disposal in terms of the absolute number of dwellings in the department (low row, left).
- Households type of dwelling of the absolute number of dwellings in the department (low row, right).

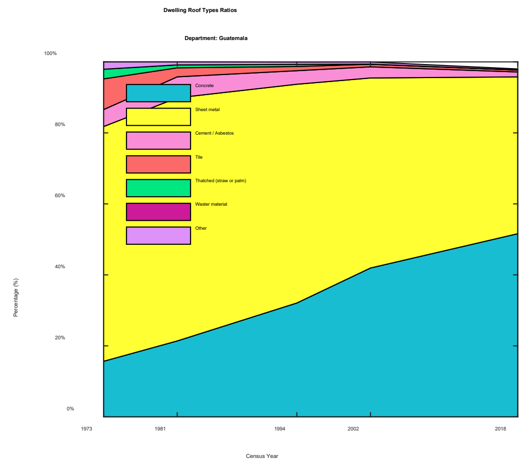
Household source of energy for cooking includes: Propane gas, Firewood (leña in Spanish), Electricity, Charcoal, Kerosene, Household doesn't cook and other. Type of drinking water supply includes: Pipeline (for one house), Pipeline (for more than two houses), Public tap, Well, Rainwater, River or Lake, Spring, Potable water delivery and other. Households Type of Lighting Source includes: Electrical network, Kerosene, Candel, Other, Solar panel or wind power. Type of Toilet includes: Toilet (connected to a drainage network), Toilet (connected to a septic tank), Bucket toilet, Pit latrine or cesspit, and does not have a toilet. Households Main Method of Garbage Disposal includes: Municipal collection, Private collection, Burning it, Burying it, Littering in water bodies, Littering on land, Compost/Recycle, Other. Type of dwelling includes: House, Apartment, Subletting room in a house, Rancho, Slum dwelling / improvised, Other, and Ignored.

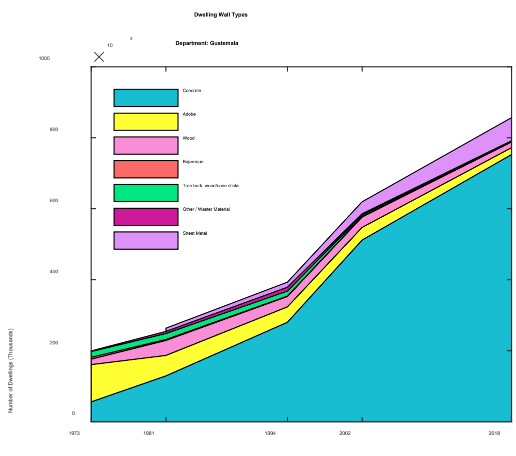
The plots of the departments of Quiché and El Progreso contain a space between the years 1973 and 1981 because it was not possible to collect the information corresponding to the 1994 census.

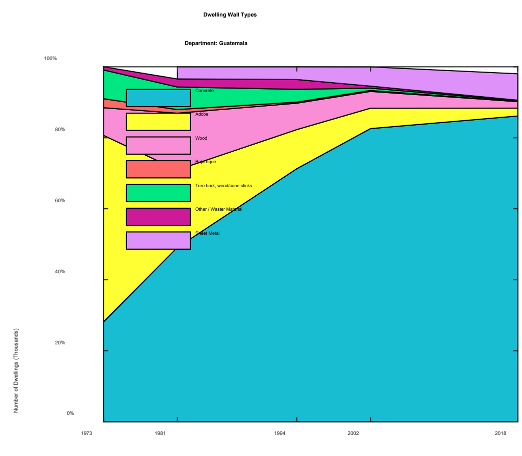
A.1. Dwelling construction materials

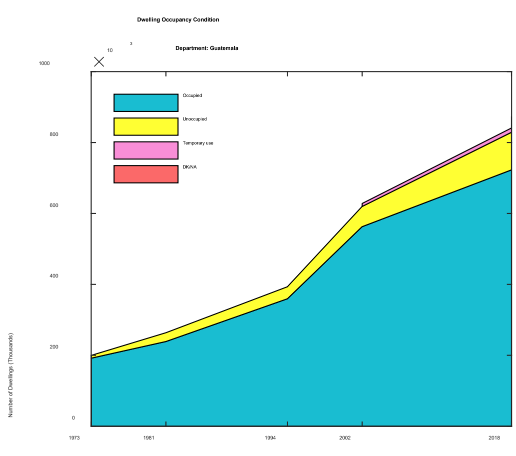
A.1.1. Department of Guatemala

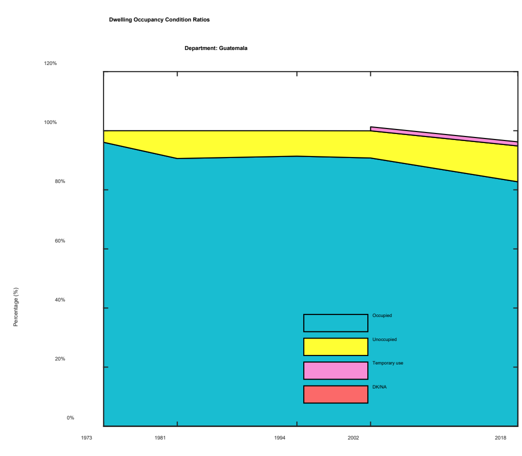












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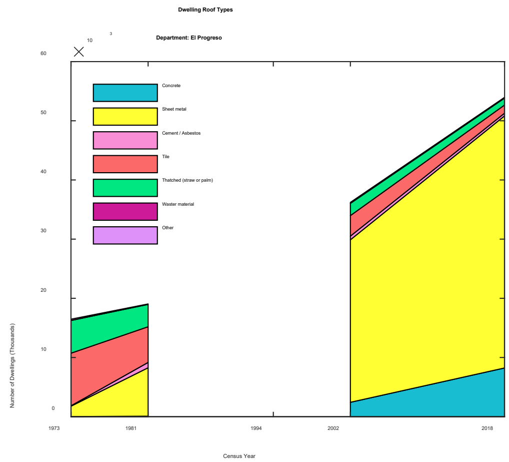

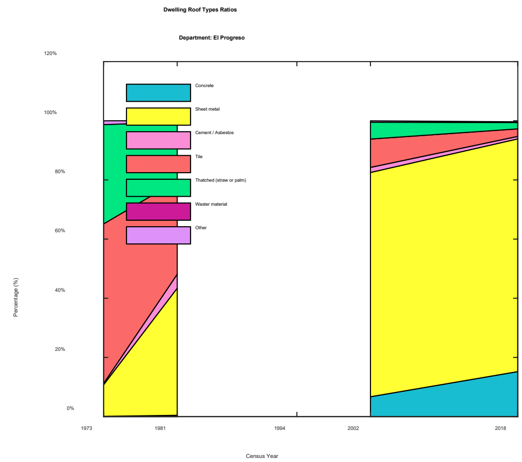

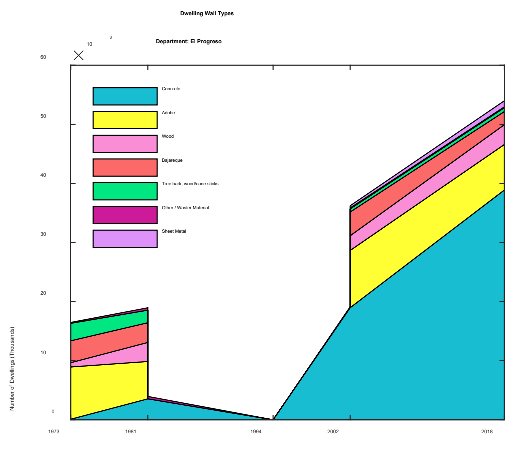

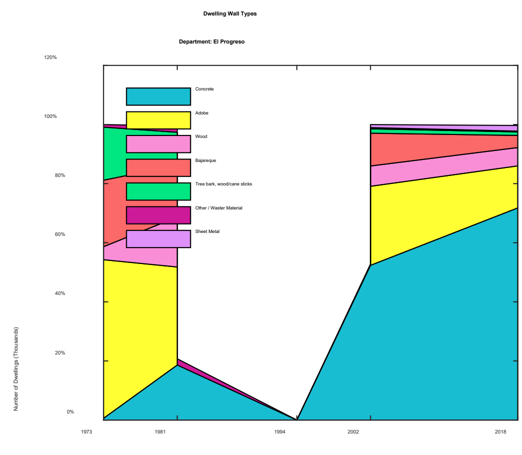

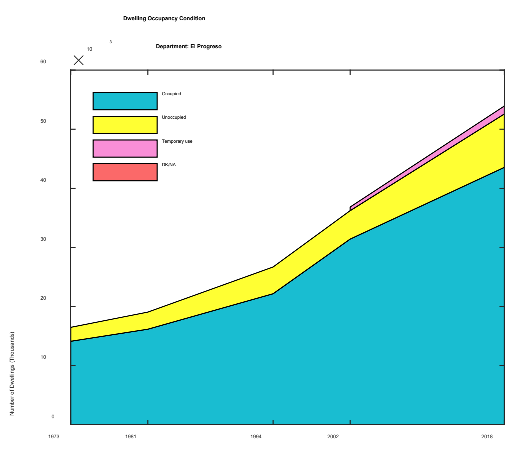

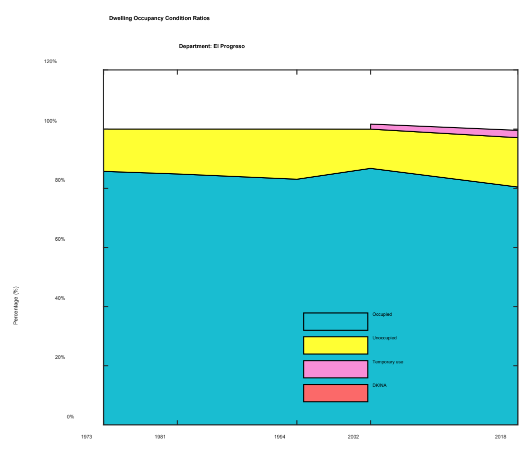

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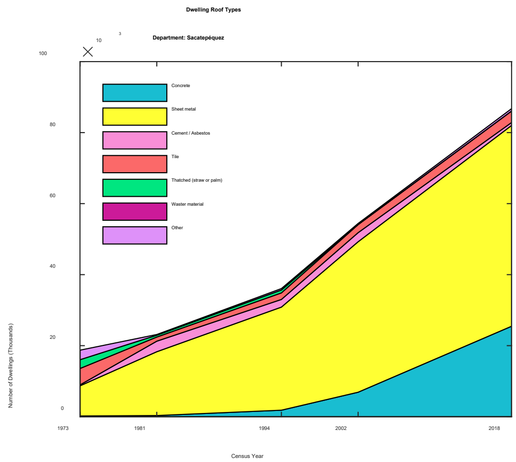

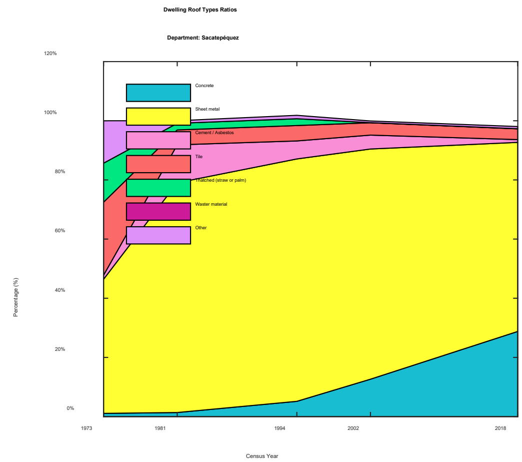

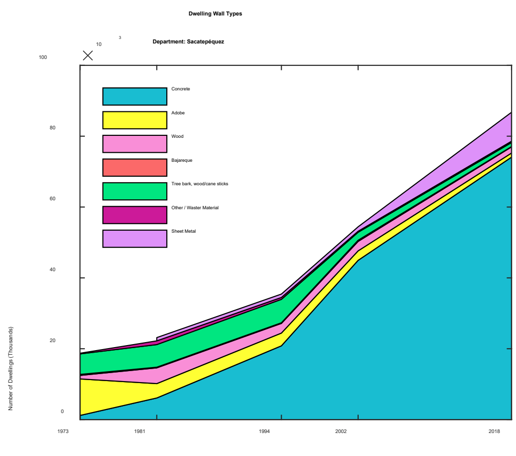

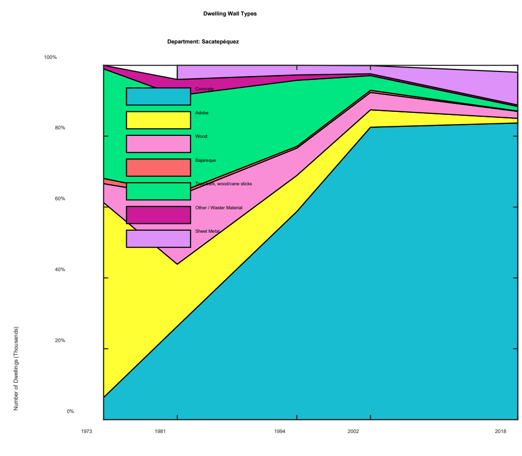

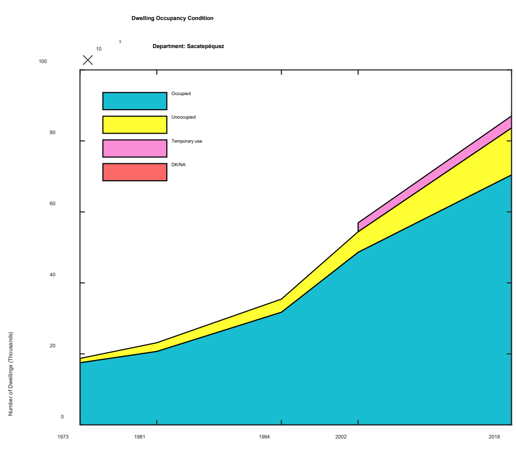

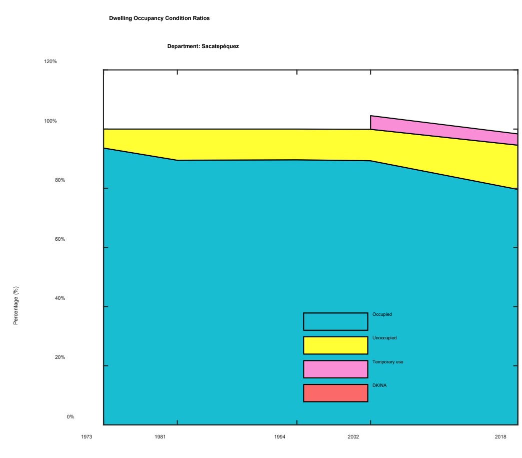

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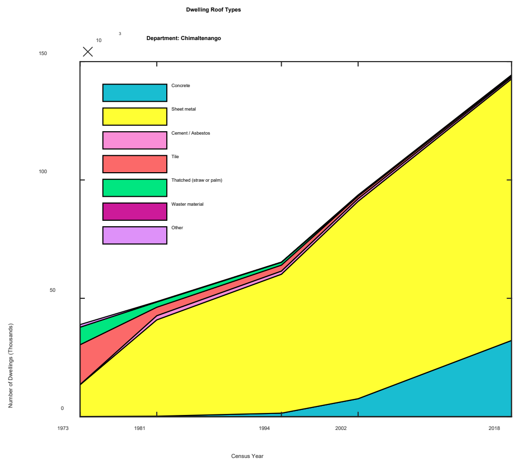

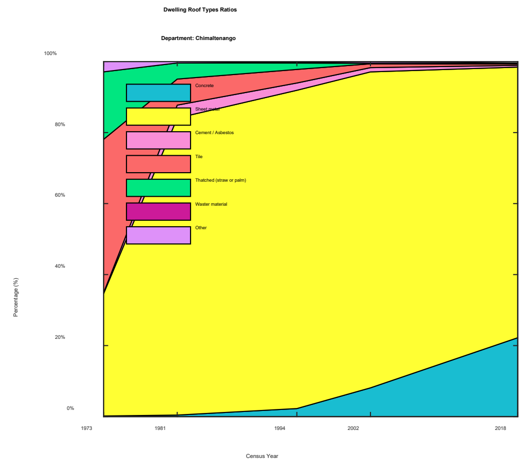

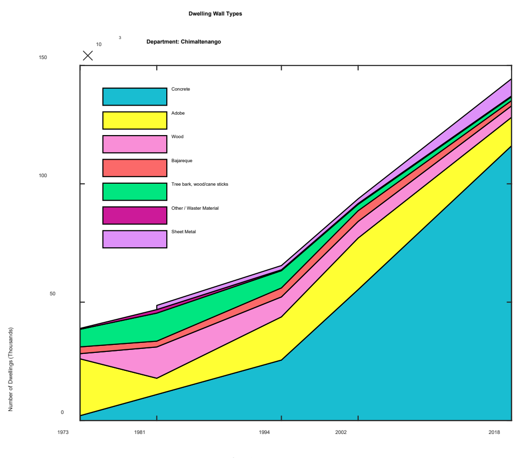

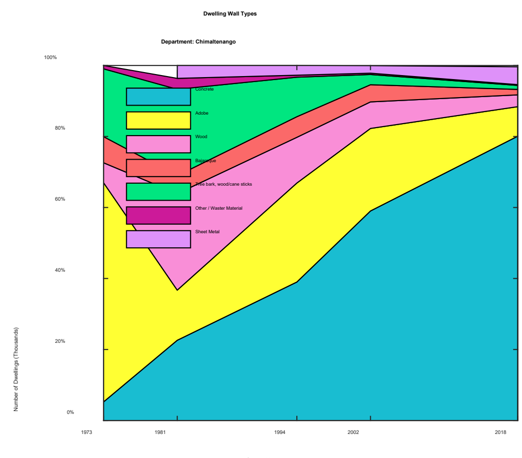

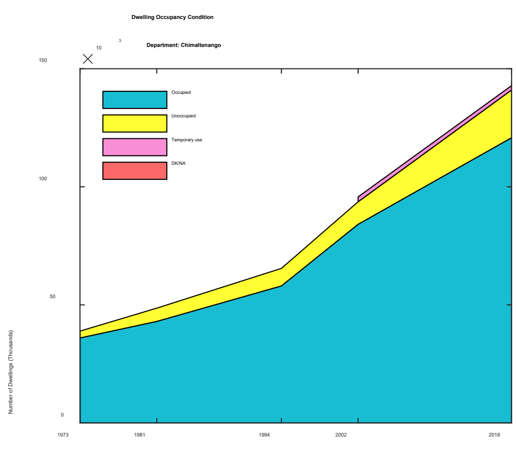

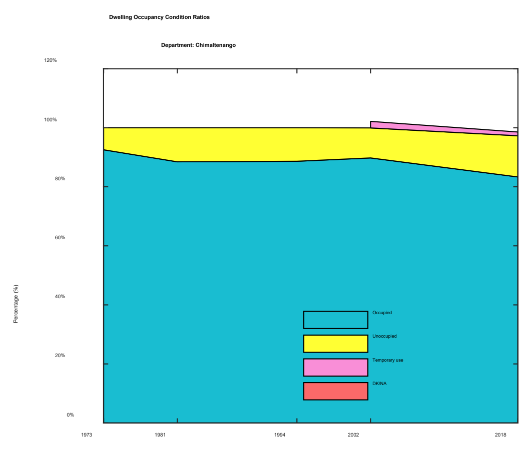

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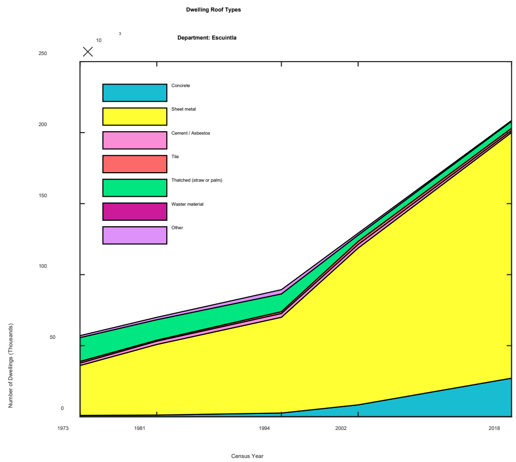

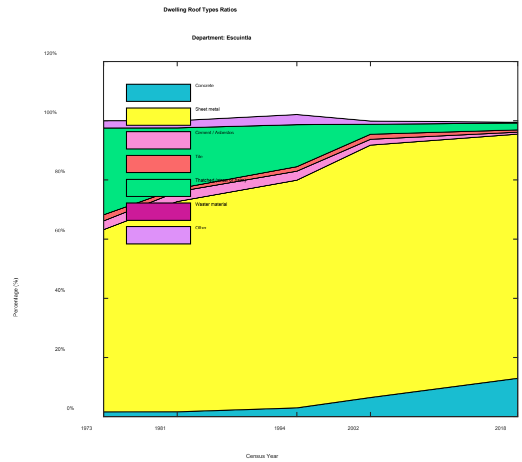

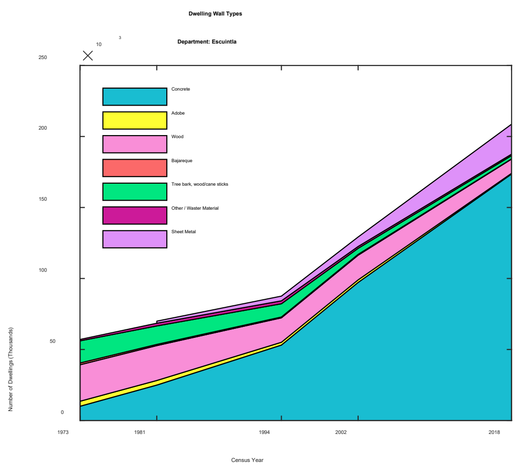

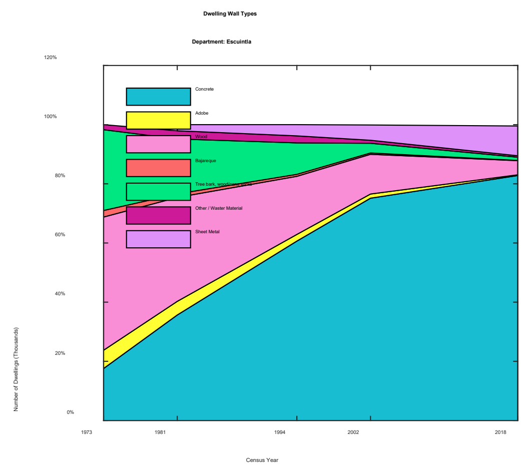

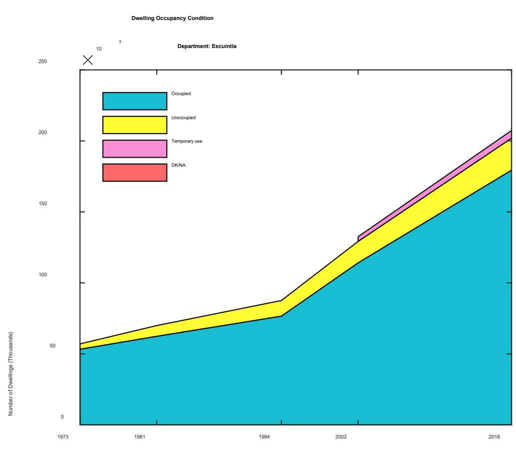

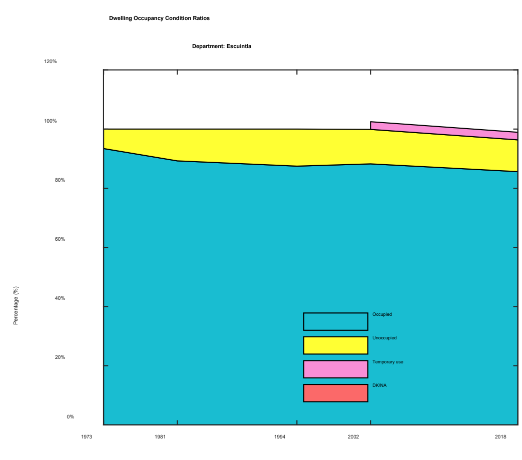

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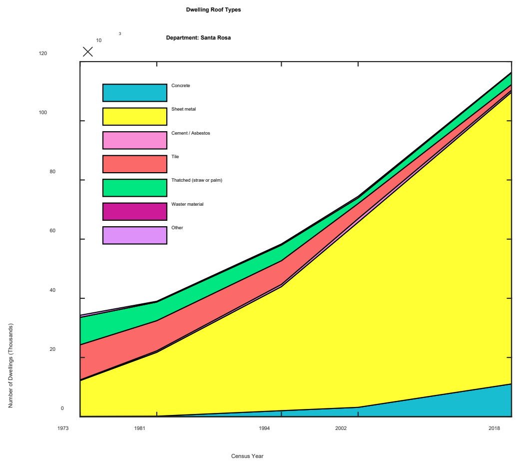

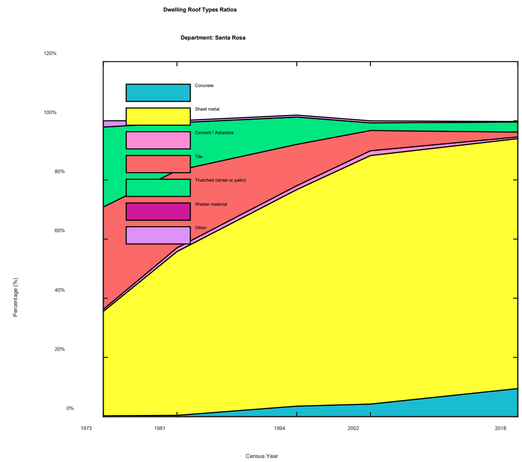

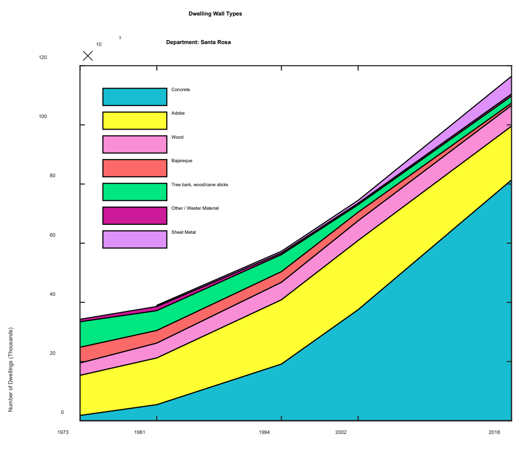

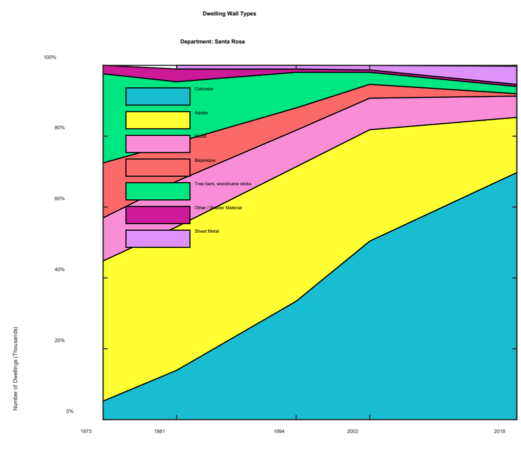

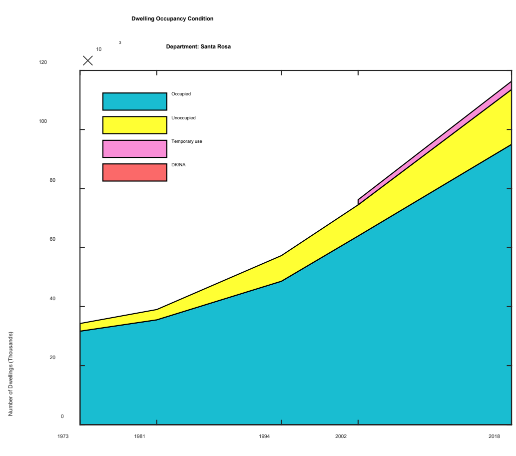

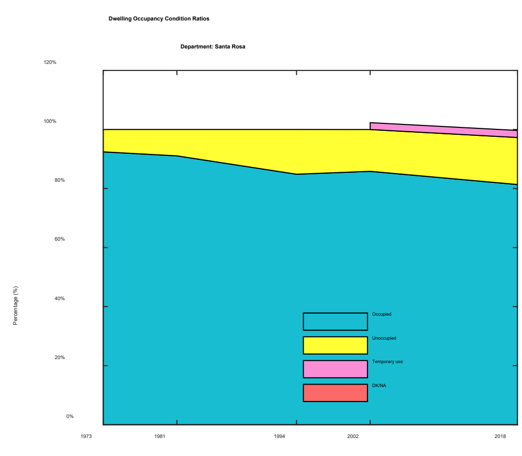

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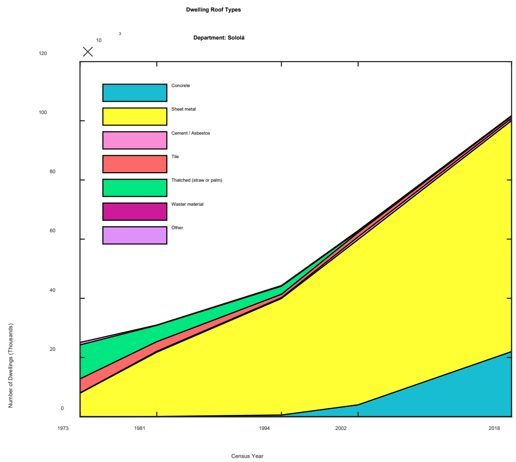
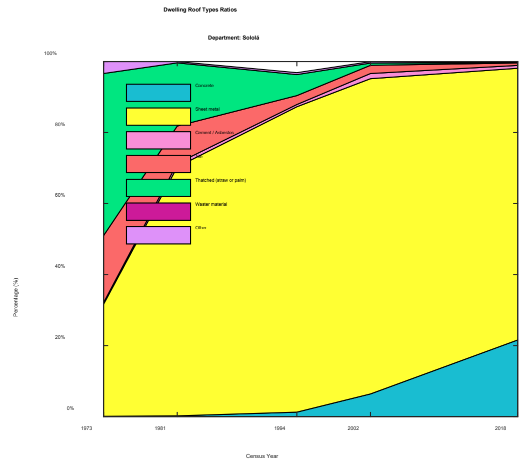
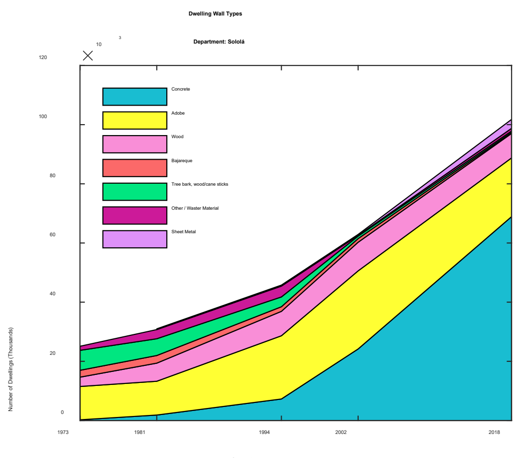
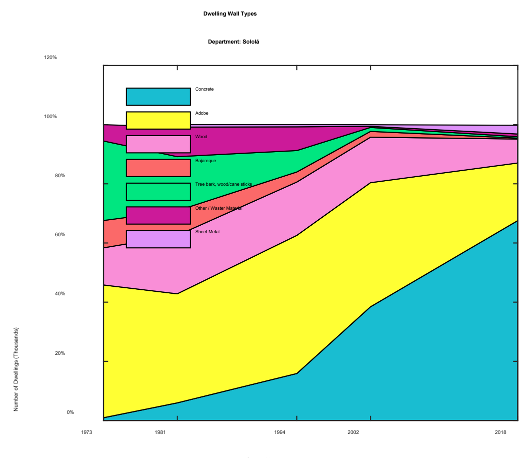

Dwelling Roof Types
Department: Sololá
10
3
Number of Dwellings (Thousands)
0
20
40
60
80
100
120
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
1973
1981
1994
2002
2018
Census Year


Dwelling Roof Types Ratios
Department: Sololá
Percentage (%)
0%
20%
40%
60%
80%
100%
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
1973
1981
1994
2002
2018
Census Year


Dwelling Wall Types
Department: Sololá
10
3
Number of Dwellings (Thousands)
0
20
40
60
80
100
120
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
1973
1981
1994
2002
2018
Census Year


Dwelling Wall Types
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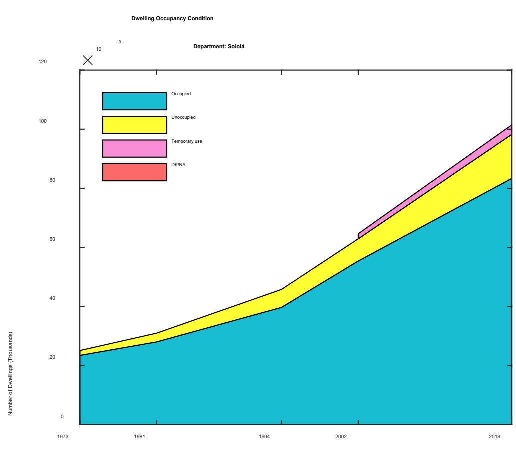
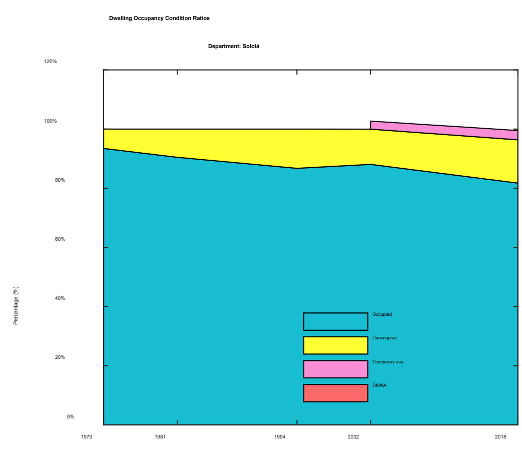
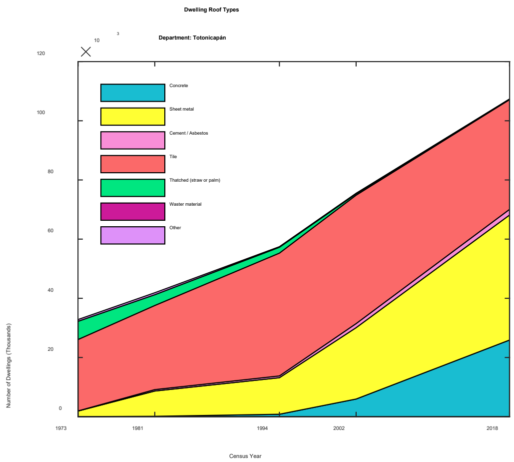
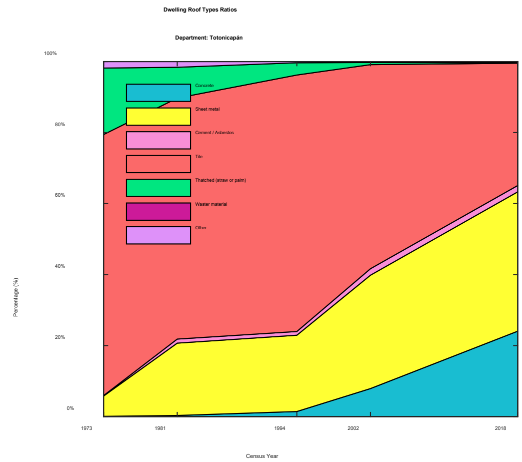
Number of Dwellings (Thousands)
0%
20%
40%
60%
80%
100%
120%
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
1973
1981
1994
2002
2018
Census Year

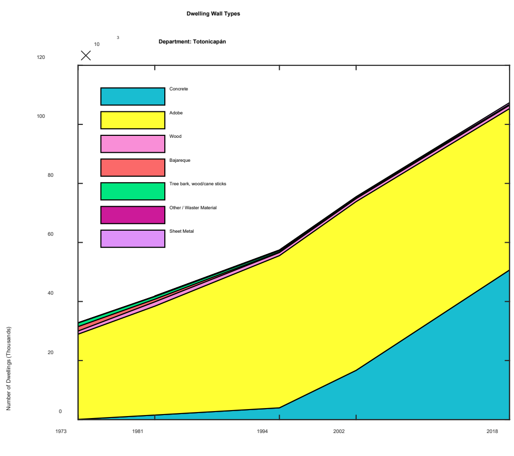

Dwelling Occupancy Condition
Department: Sololá
10
3
Number of Dwellings (Thousands)
0
20
40
60
80
100
120
Occupied
Unoccupied
Temporary use
DK/NA
1973
1981
1994
2002
2018
Census Year

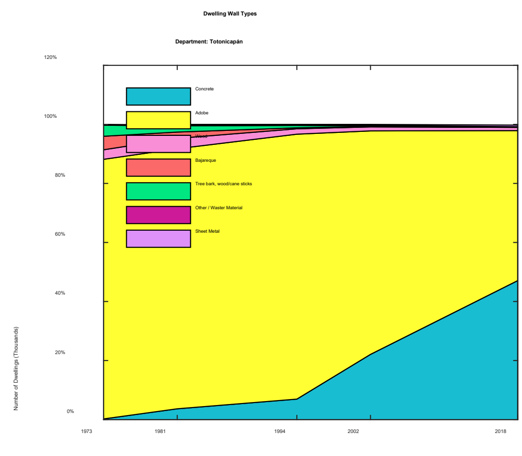

Dwelling Occupancy Condition Ratios
Department: Sololá
Percentage (%)
0%
20%
40%
60%
80%
100%
120%
Occupied
Unoccupied
Temporary use
DK/NA
1973
1981
1994
2002
2018
Census Year

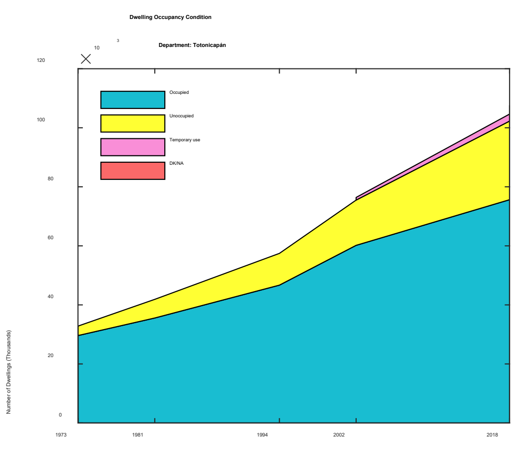
A.1.8. Totonicapán

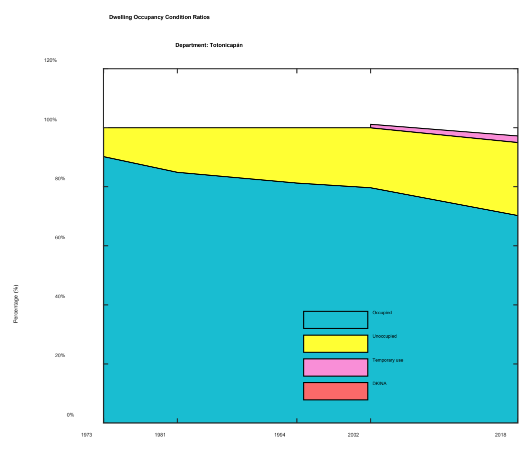












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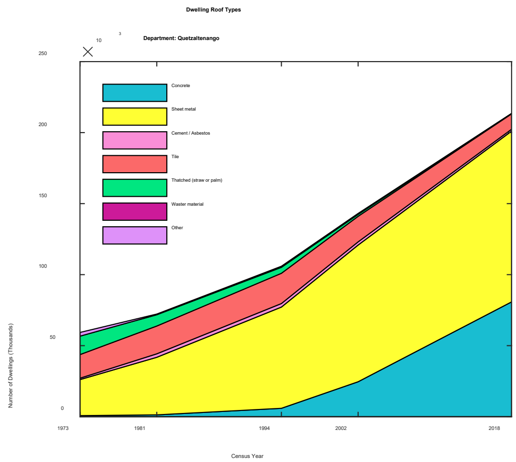
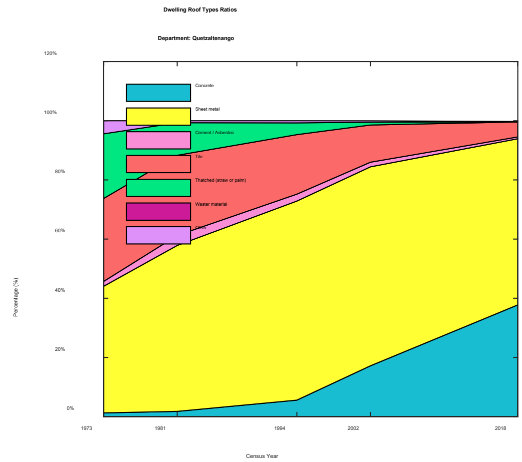
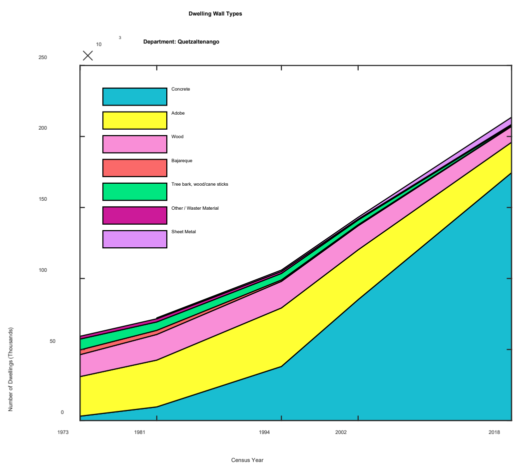
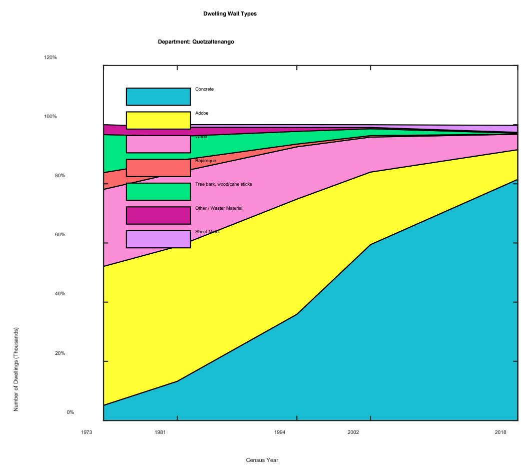
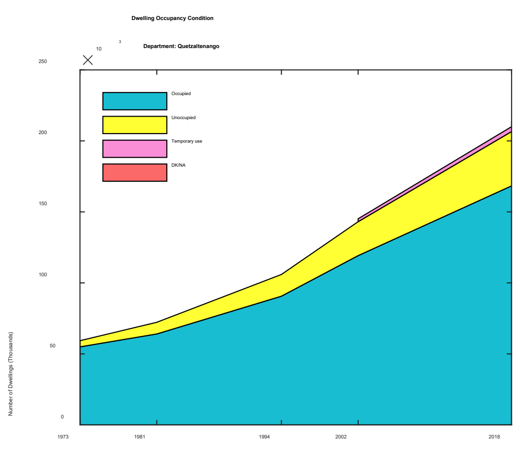
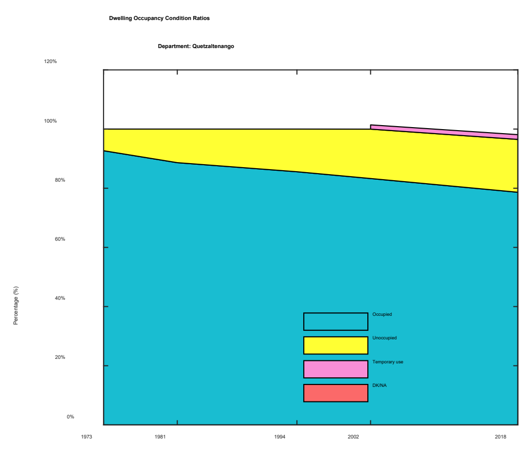




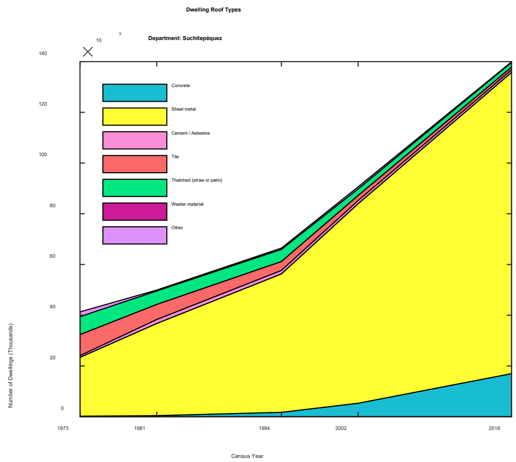


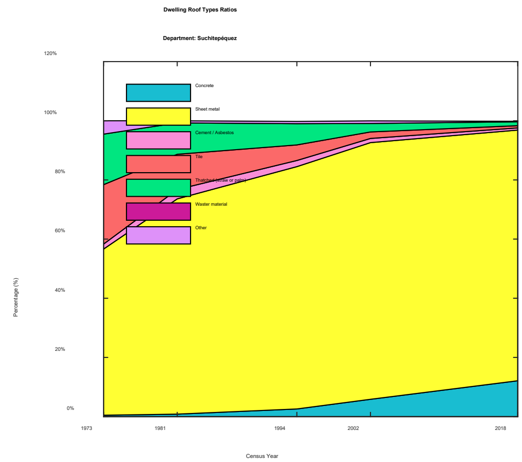


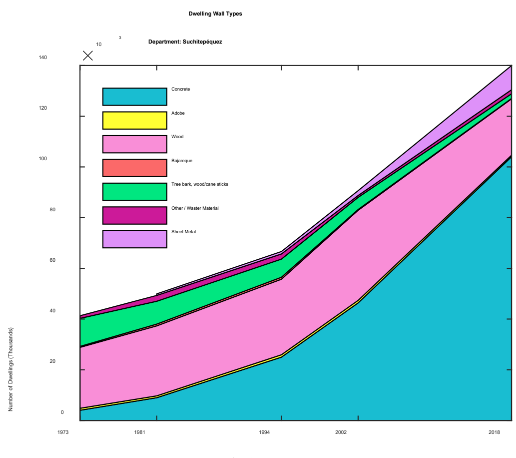


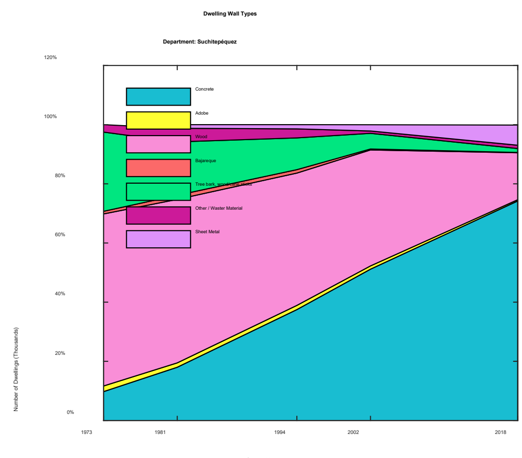


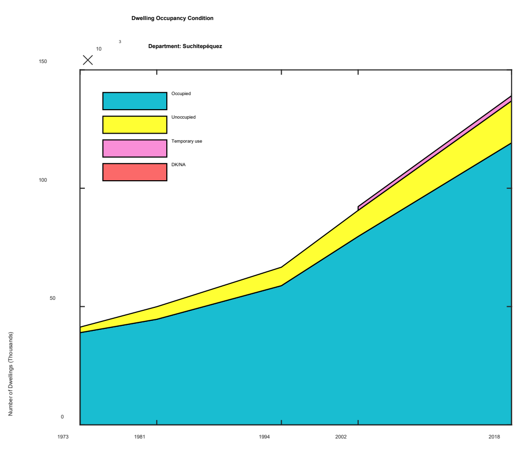
A.1.10. Suchitepequez

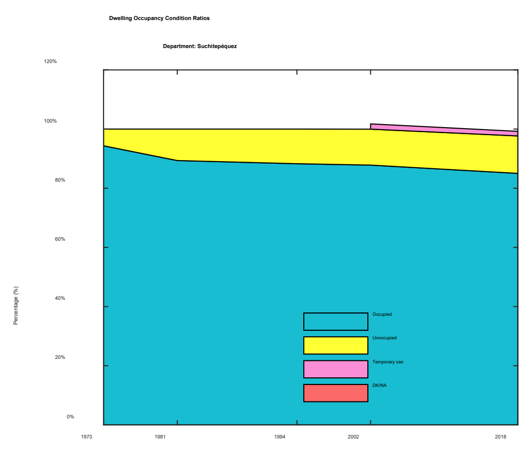




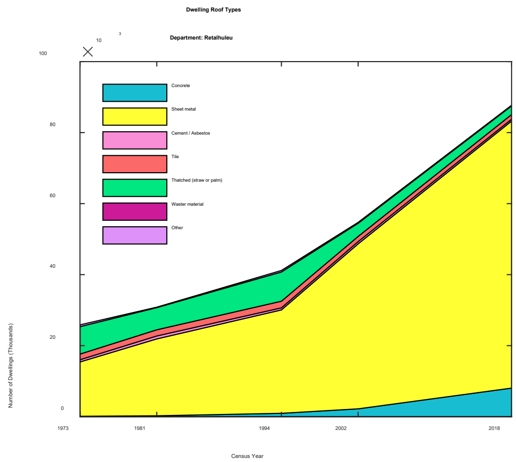


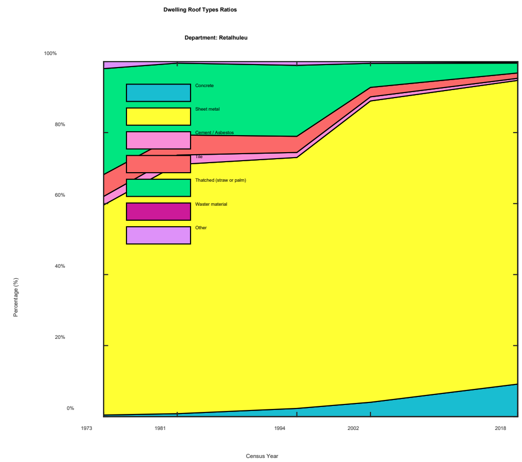


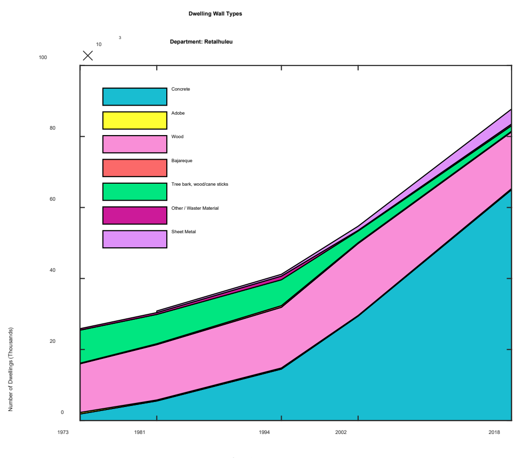


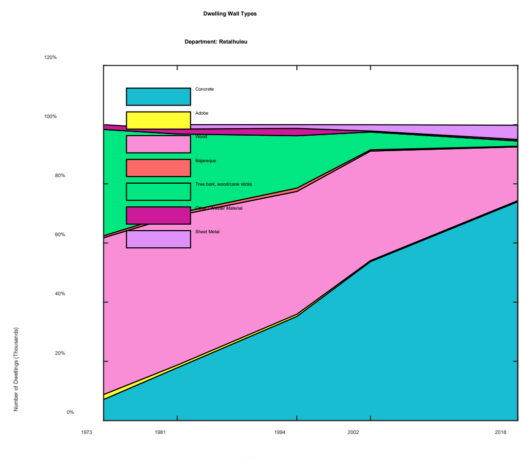


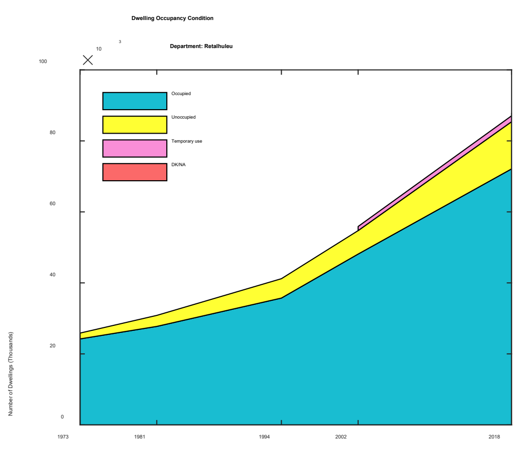
A.1.11. Retalhuleu

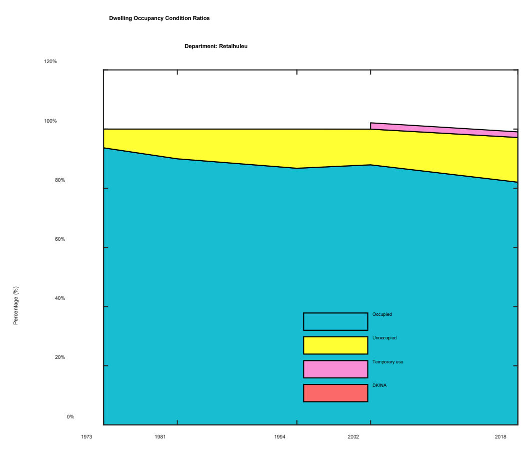




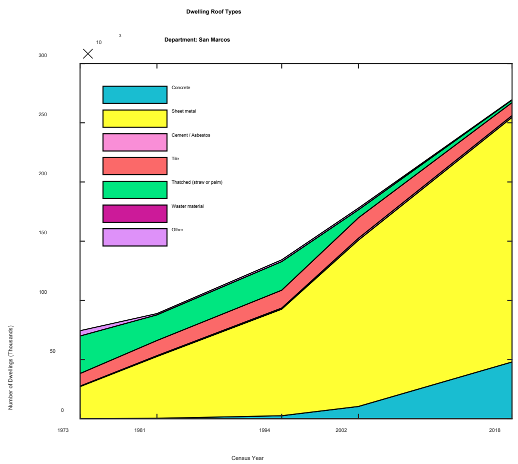


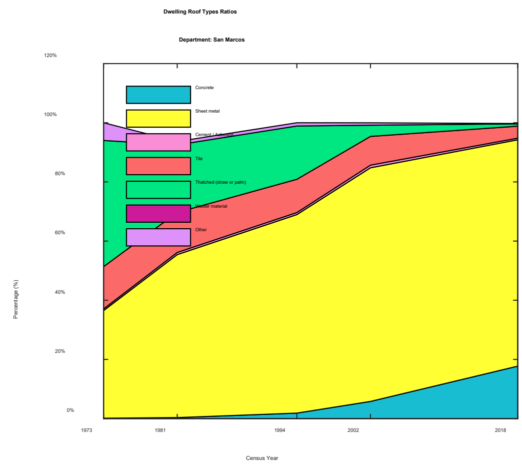


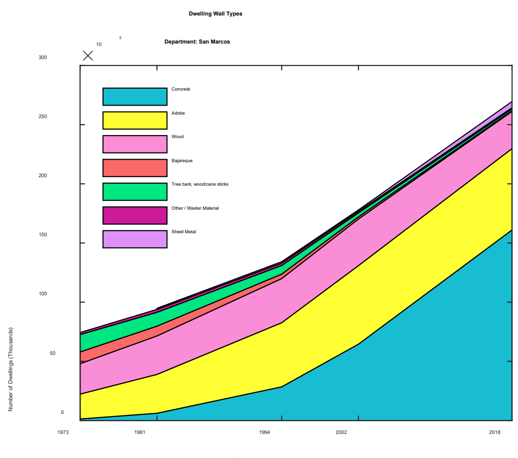


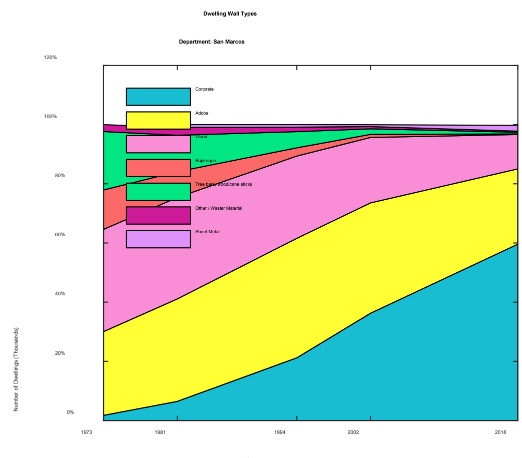


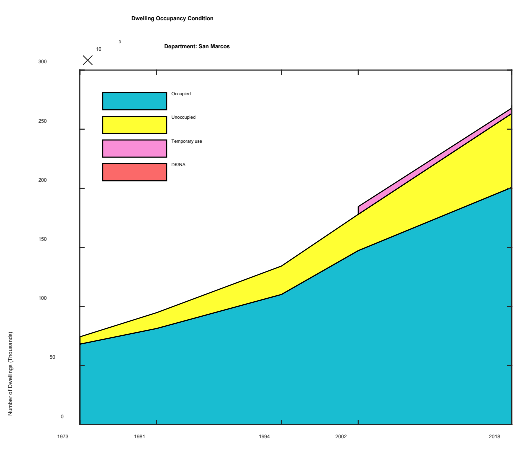
A.1.12. San Marcos

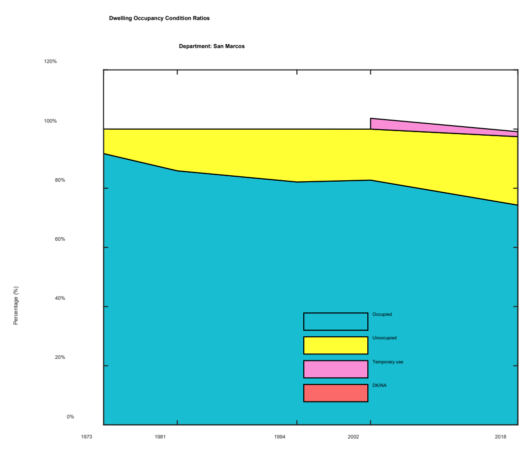




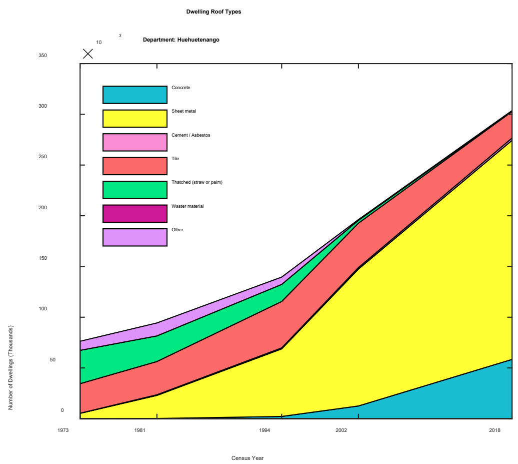


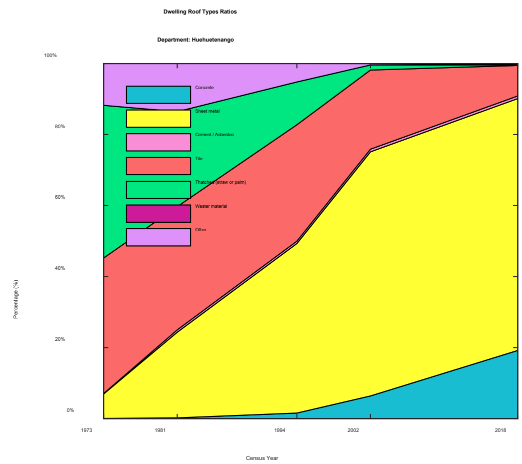


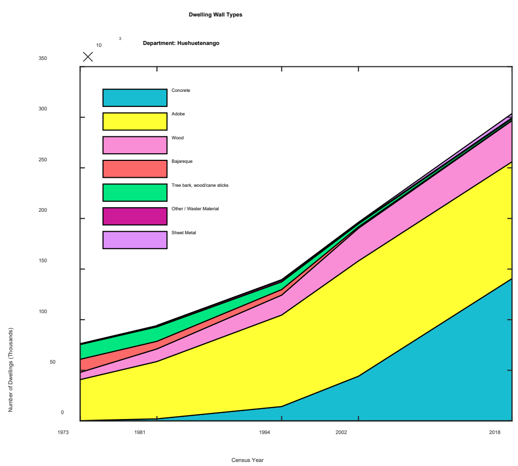


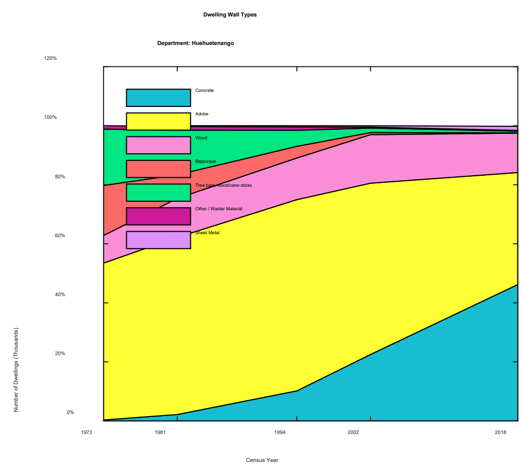


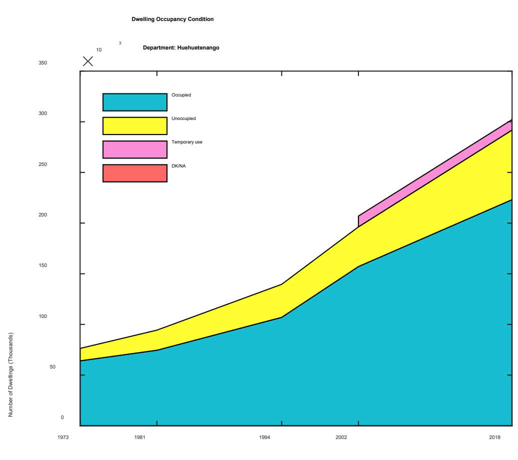
A.1.13. Huehuetenango

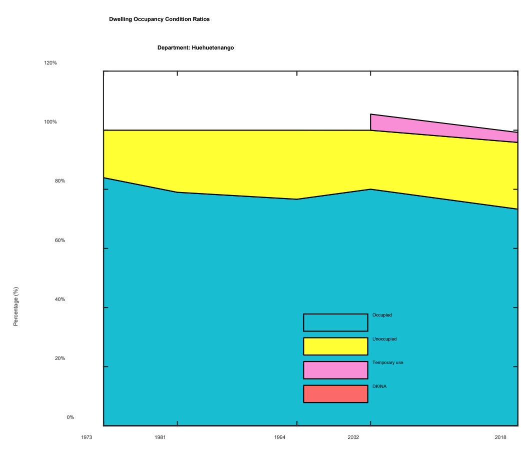




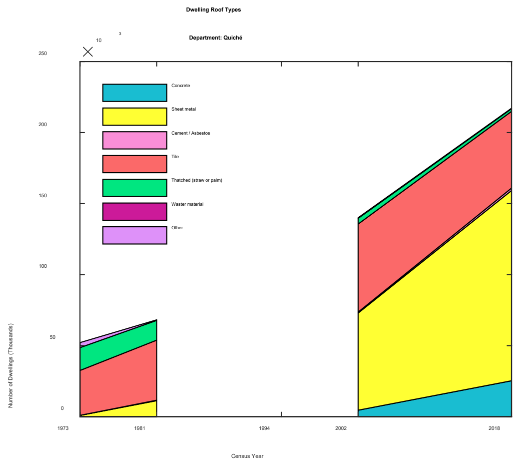




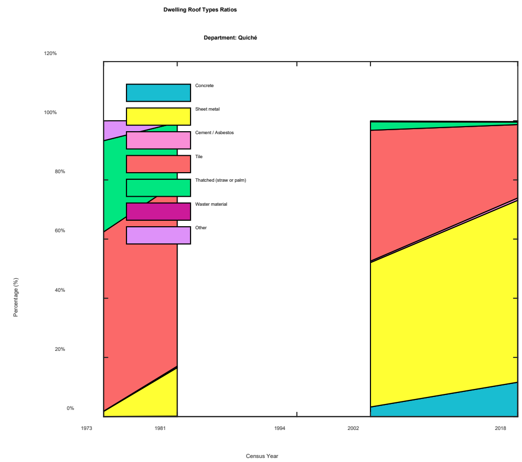




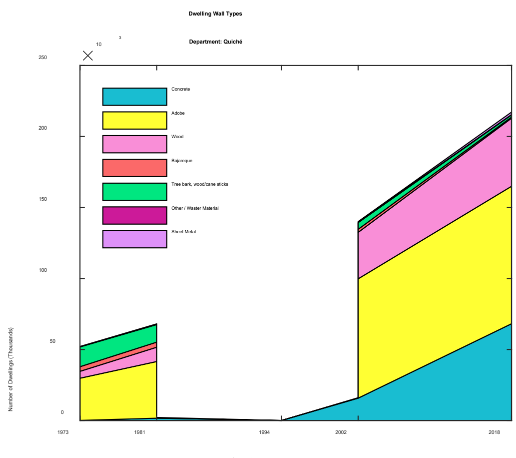
A.1.14. Quiché



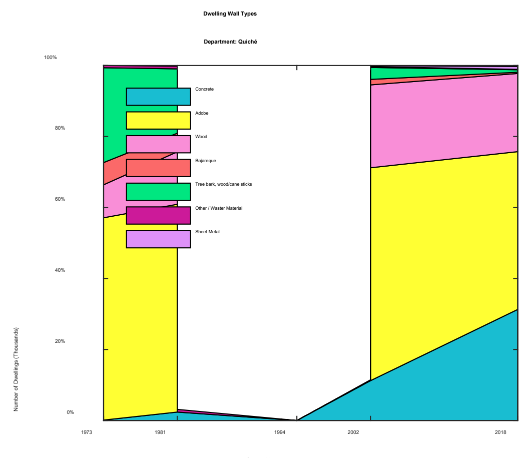
Dwelling Roof Types
Department: Quiché
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
Number of Dwellings (Thousands)
Census Year



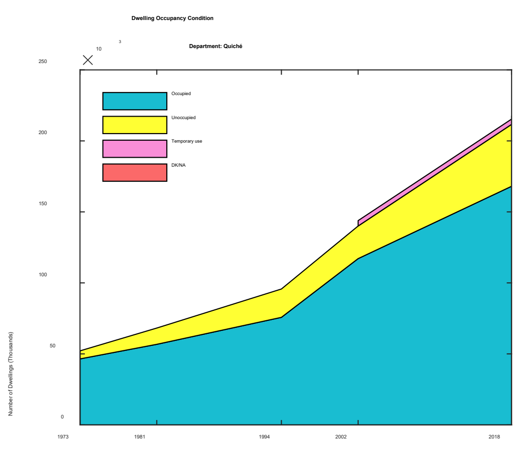
Dwelling Roof Types Ratios
Department: Quiché
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
Percentage (%)
Census Year



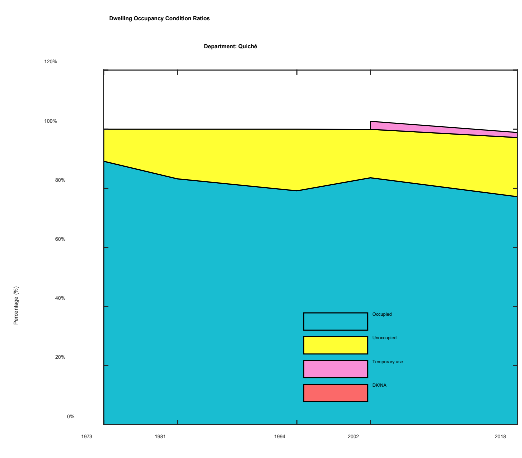
Dwelling Wall Types
Department: Quiché
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
Number of Dwellings (Thousands)
Census Year



Dwelling Wall Types
Department: Quiché
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
Number of Dwellings (Thousands)
Census Year

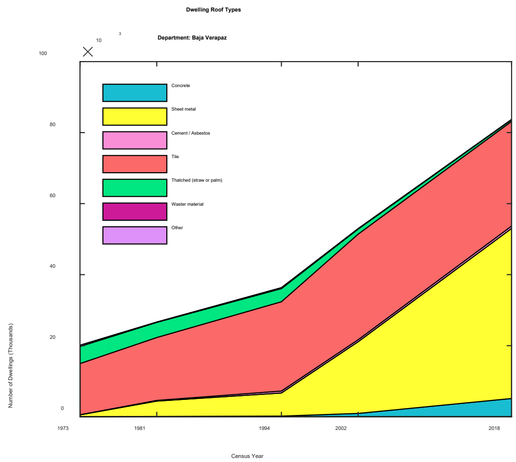


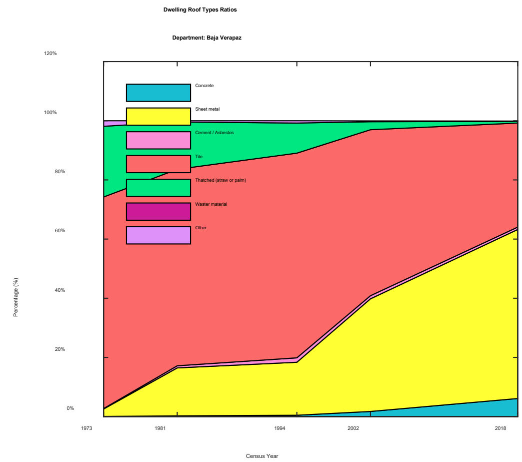
Dwelling Occupancy Condition
Department: Quiché
Occupied
Unoccupied
Temporary use
DK/NA
Number of Dwellings (Thousands)
Census Year

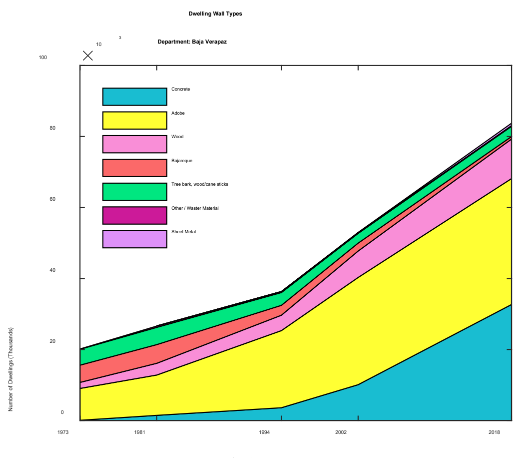


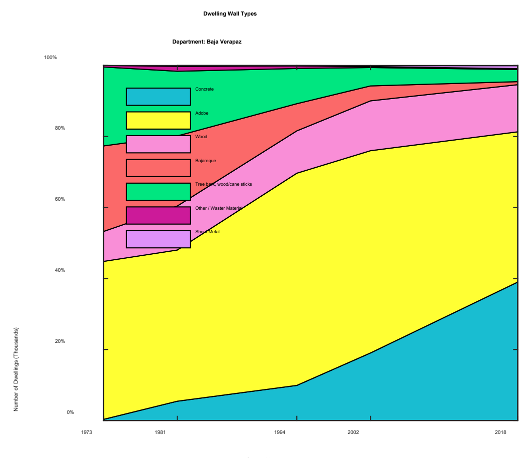
Dwelling Occupancy Condition Ratios
Department: Quiché
Occupied
Unoccupied
Temporary use
DK/NA
Percentage (%)
Census Year

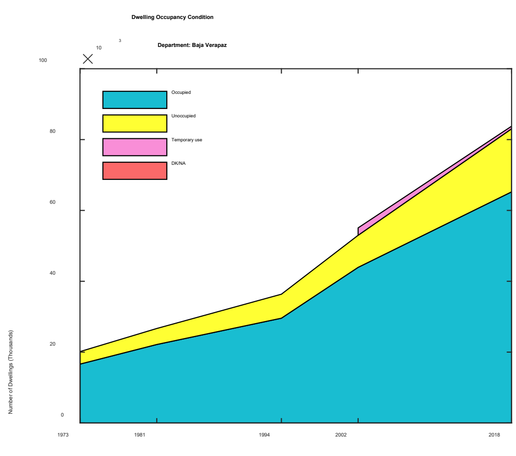
A.1.15. Baja Verapaz

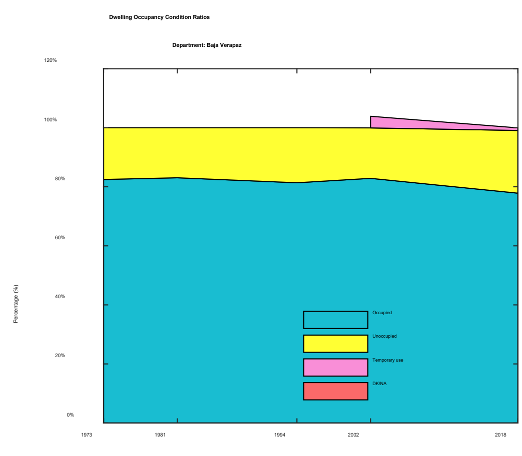




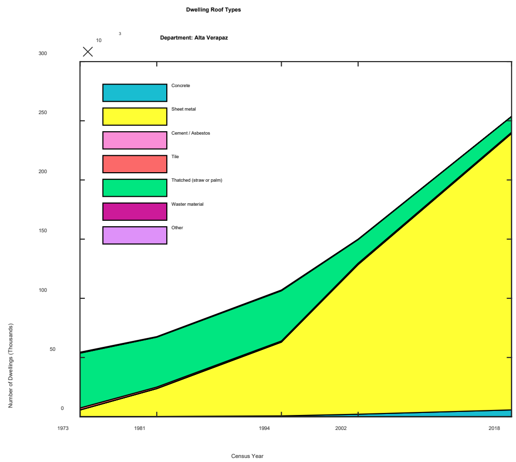


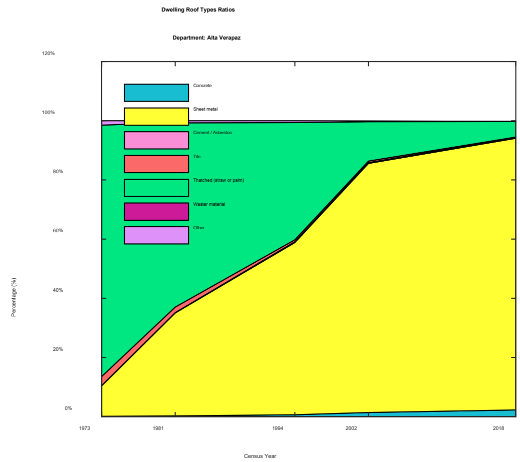


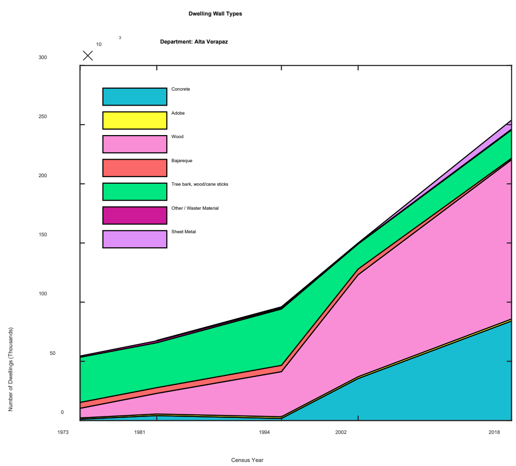


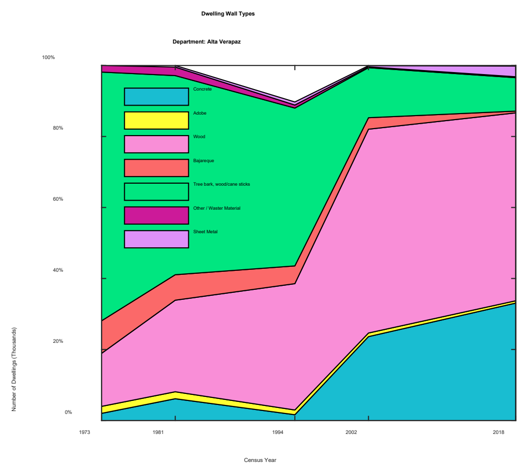


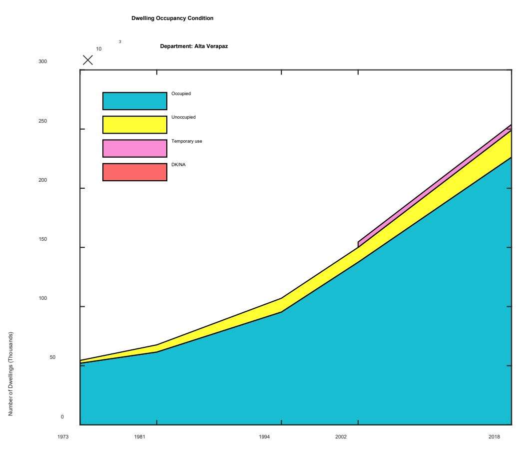
A.1.16. Alta Verapaz

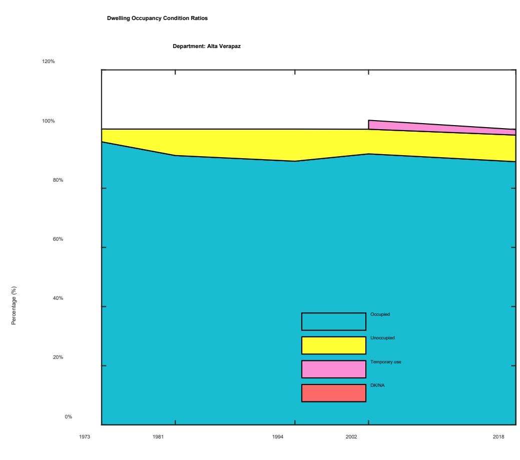




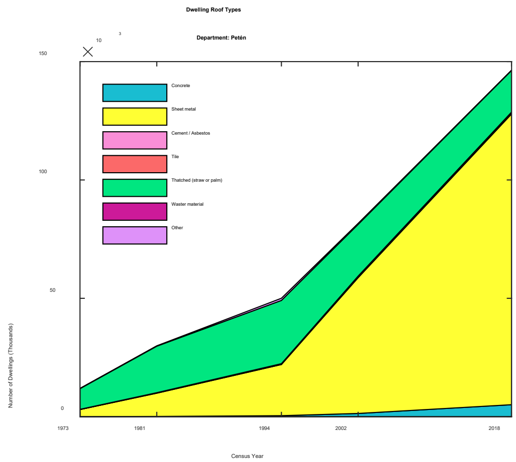


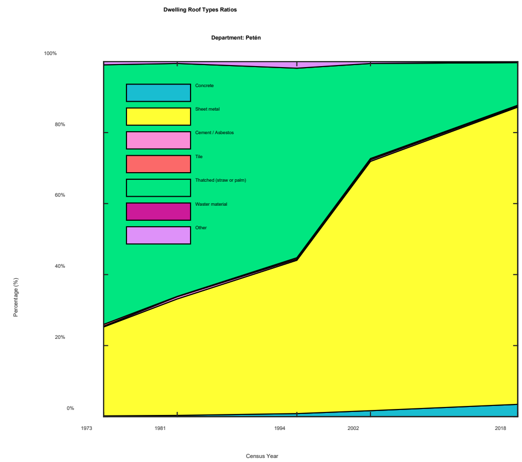


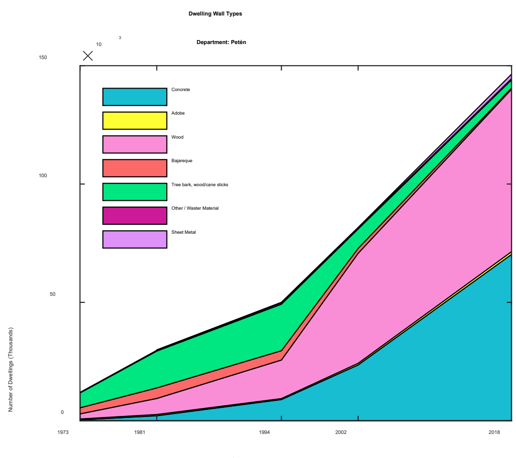


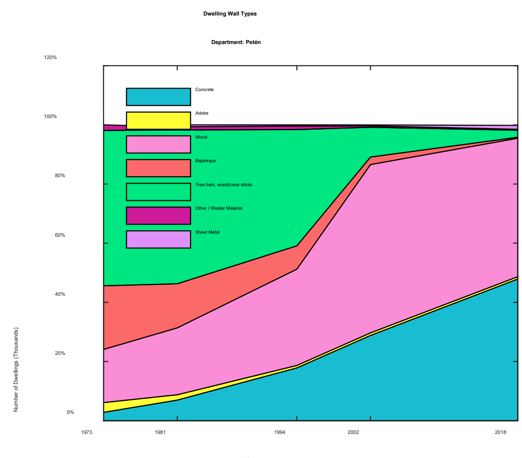


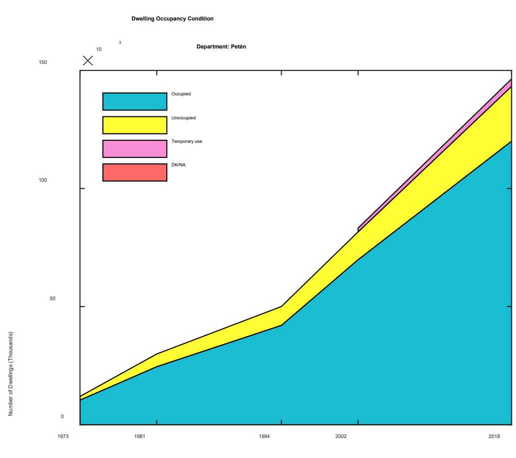
A.1.17. Petén

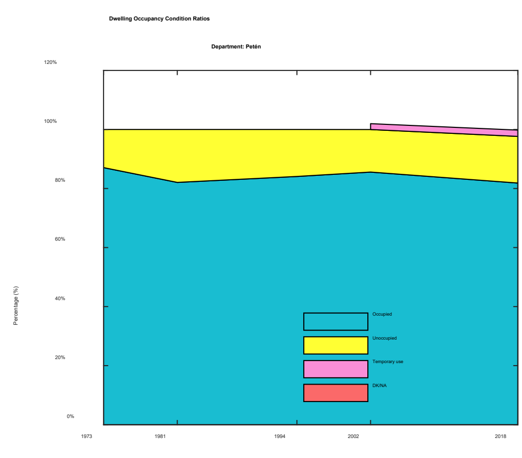

Dwelling Roof Types
Department: Petén
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
Number of Dwellings (Thousands)
Census Year


Dwelling Roof Types Ratios
Department: Petén
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
Percentage (%)
Census Year

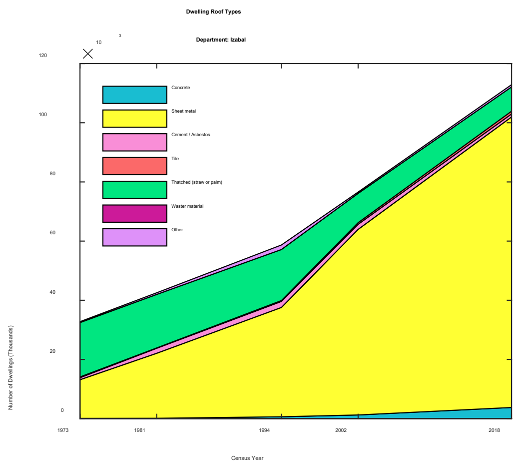

Dwelling Wall Types
Department: Petén
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
Number of Dwellings (Thousands)
Census Year

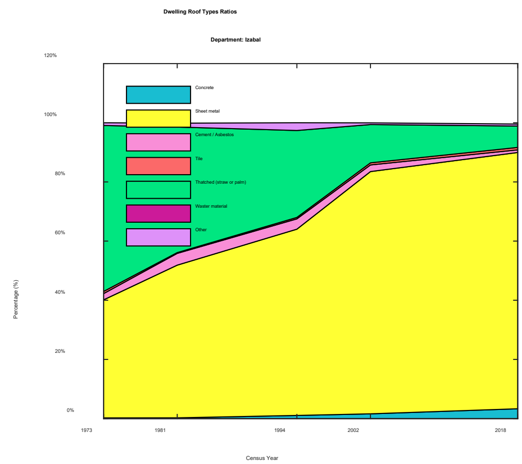

Dwelling Wall Types
Department: Petén
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
Number of Dwellings (Thousands)
Census Year

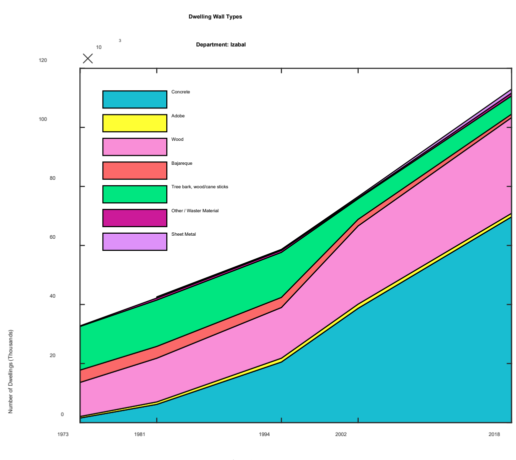

Dwelling Occupancy Condition
Department: Petén
Occupied
Unoccupied
Temporary use
DK/NA
Number of Dwellings (Thousands)
Census Year

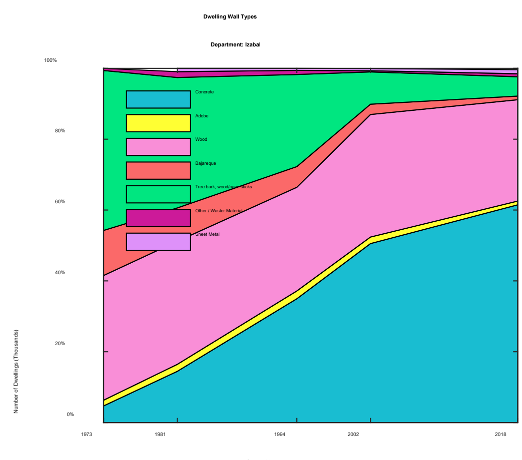

Dwelling Occupancy Condition Ratios
Department: Petén
Occupied
Unoccupied
Temporary use
DK/NA
Percentage (%)
Census Year

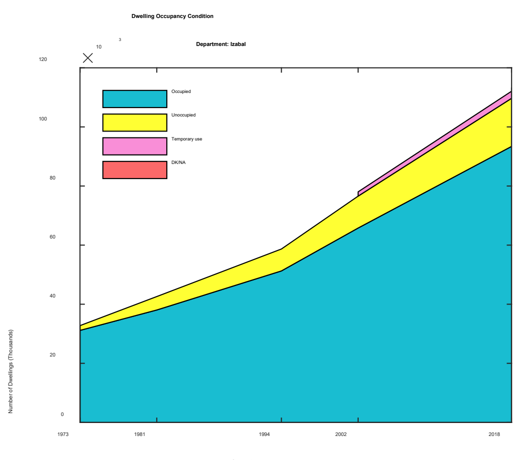
A.1.18. Izabal

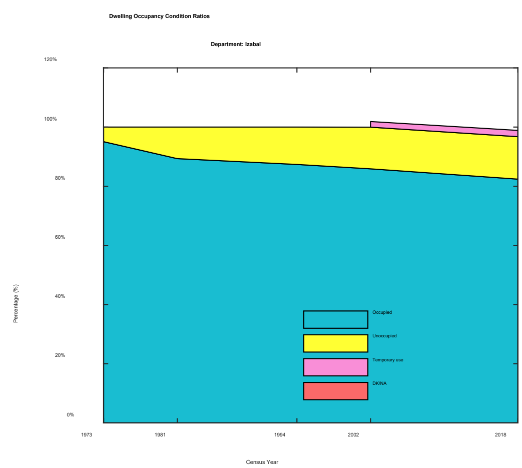

Dwelling Roof Types
Department: Izabal
10 3
120
100
80
60
40
20
0
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other


Dwelling Roof Types Ratios
Department: Izabal
120%
100%
80%
60%
40%
20%
0%
Percentage (%)
1973
1981
1994
2002
2018
Census Year
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other

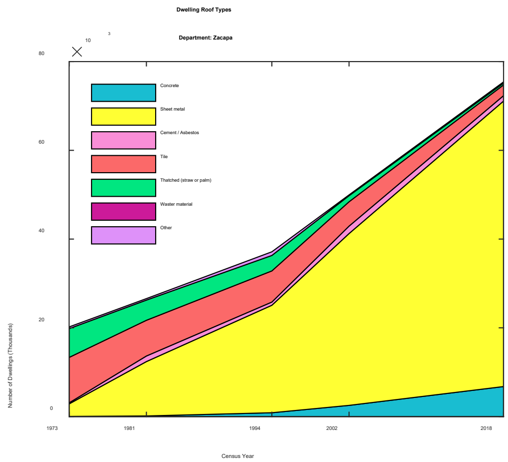

Dwelling Wall Types
Department: Izabal
10 3
120
100
80
60
40
20
0
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal


Dwelling Wall Types
Department: Izabal
100%
80%
60%
40%
20%
0%
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal

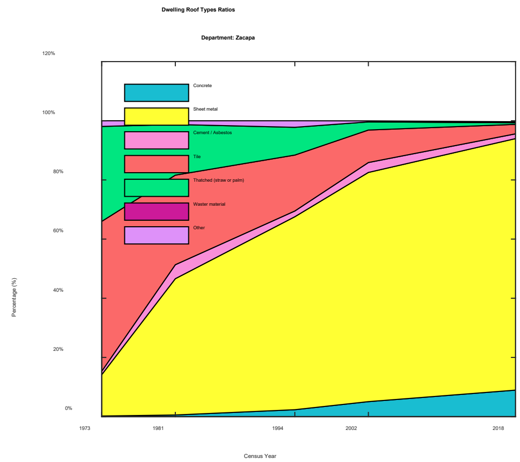

Dwelling Occupancy Condition
Department: Izabal
10 3
120
100
80
60
40
20
0
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year
Occupied
Unoccupied
Temporary use
DK/NA


Dwelling Occupancy Condition Ratios
Department: Izabal
120%
100%
80%
60%
40%
20%
0%
Percentage (%)
1973
1981
1994
2002
2018
Census Year
Occupied
Unoccupied
Temporary use
DK/NA

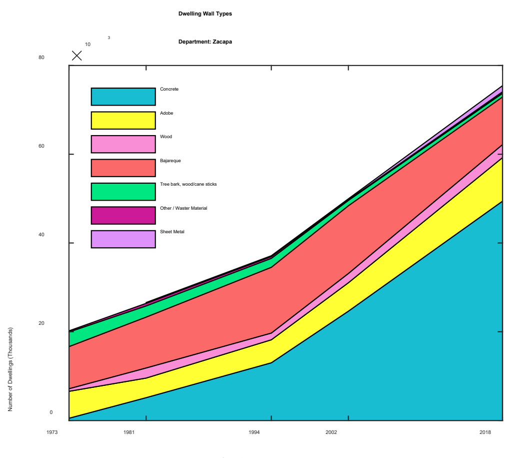
A.1.19. Zacapa



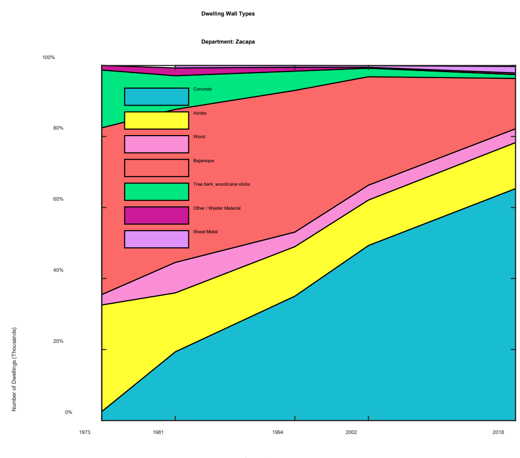
Dwelling Roof Types
Department: Zacapa
10
3
80
60
40
20
0
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year



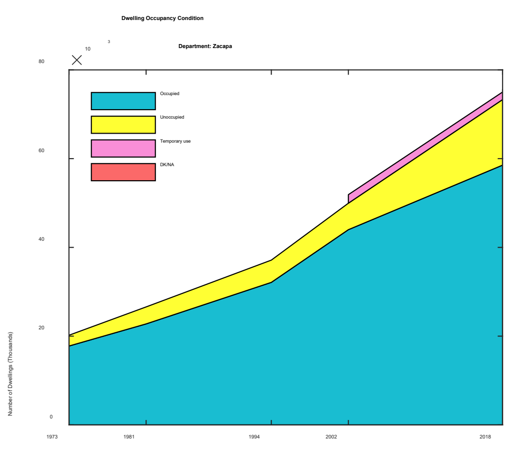
Dwelling Roof Types Ratios
Department: Zacapa
120%
100%
80%
60%
40%
20%
0%
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Waster material
Other
Percentage (%)
1973
1981
1994
2002
2018
Census Year



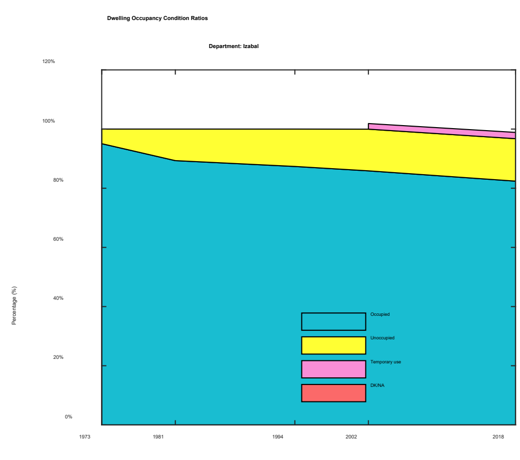
Dwelling Wall Types
Department: Zacapa
10
3
80
60
40
20
0
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year



Dwelling Wall Types
Department: Zacapa
100%
80%
60%
40%
20%
0%
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Waster Material
Sheet Metal
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year

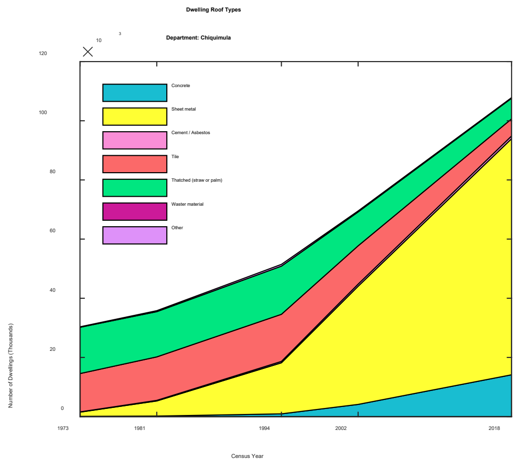


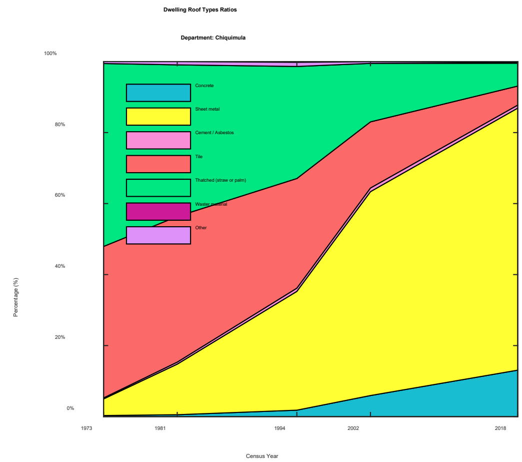
Dwelling Occupancy Condition
Department: Zacapa
10
3
80
60
40
20
0
Occupied
Unoccupied
Temporary use
DK/NA
Number of Dwellings (Thousands)
1973
1981
1994
2002
2018
Census Year

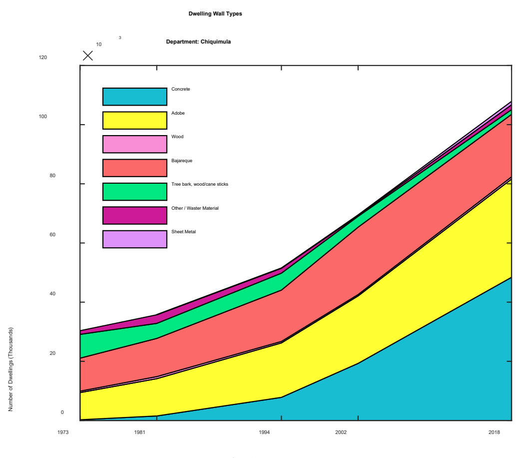


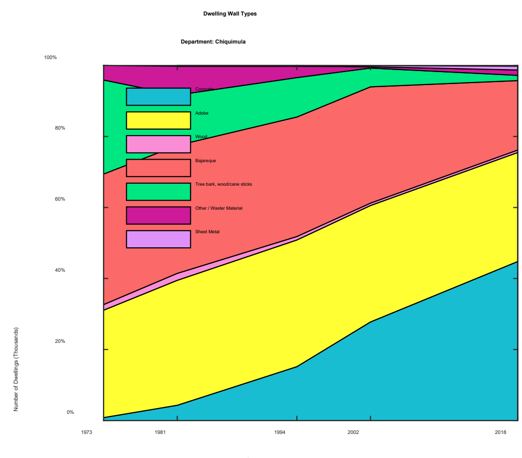
Dwelling Occupancy Condition Ratios
Department: Izabal
120%
100%
80%
60%
40%
20%
0%
Occupied
Unoccupied
Temporary use
DK/NA
Percentage (%)
1973
1981
1994
2002
2018
Census Year

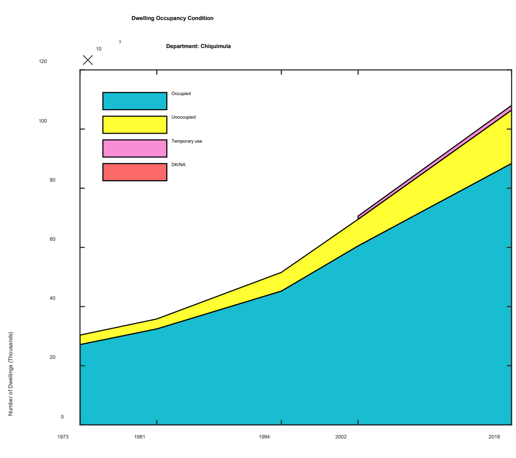
A.1.20. Chiquimula

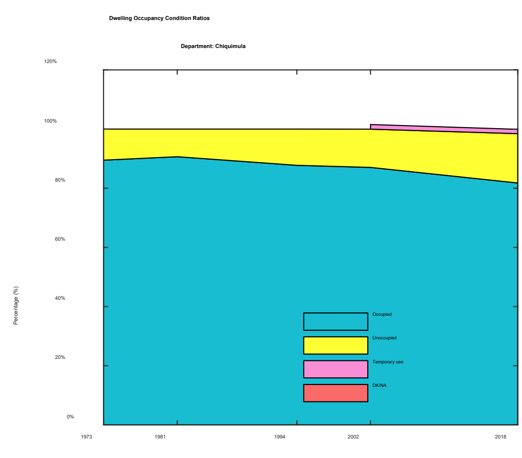




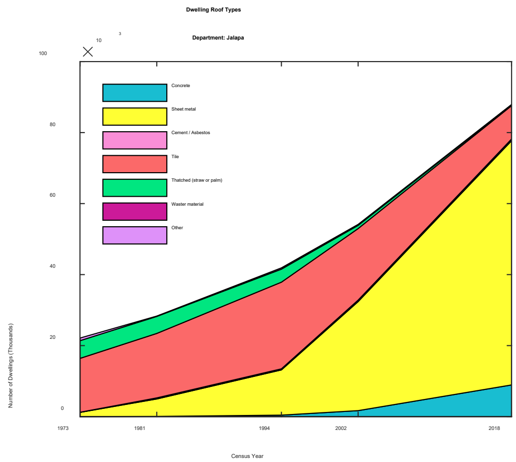


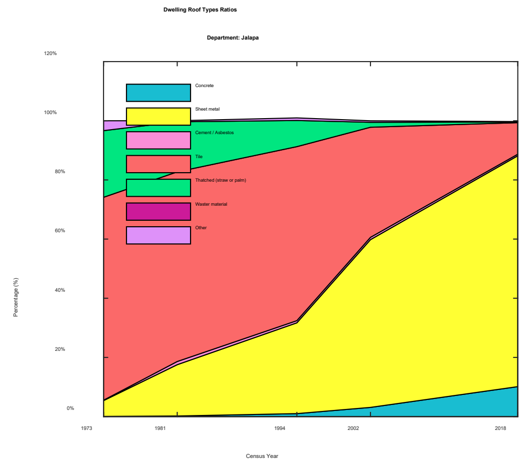


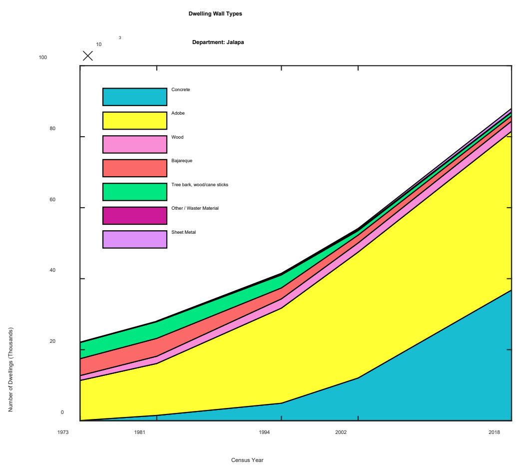


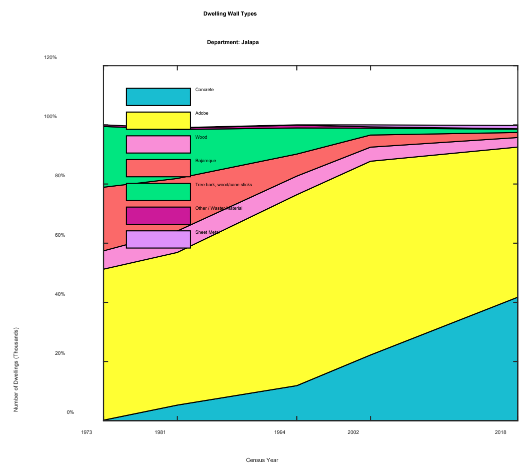


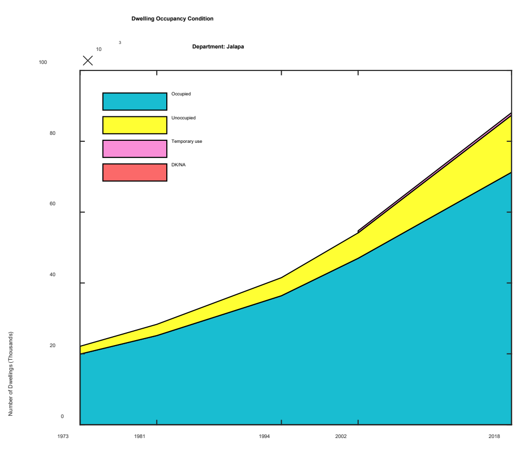
A.1.21. Jalapa

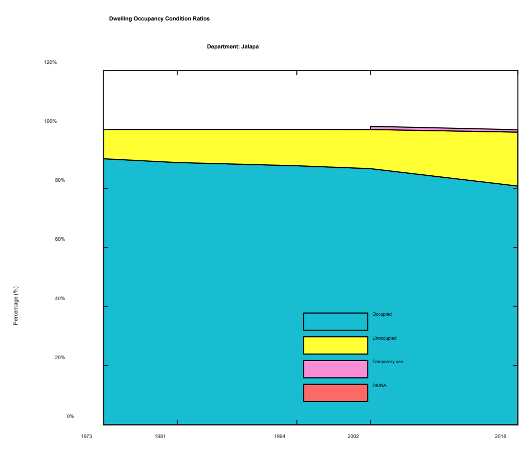

Dwelling Roof Types
Department: Jalapa
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Wastee material
Other
Number of Dwellings (Thousands)
Census Year
1973
1981
1994
2002
2018


Dwelling Roof Types Ratios
Department: Jalapa
Concrete
Sheet metal
Cement / Asbestos
Tile
Thatched (straw or palm)
Wastee material
Other
Percentage (%)
Census Year

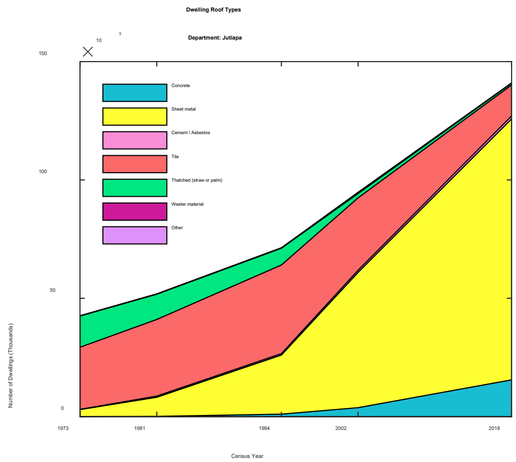

Dwelling Wall Types
Department: Jalapa
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Wastee Material
Sheet Metal
Number of Dwellings (Thousands)
Census Year

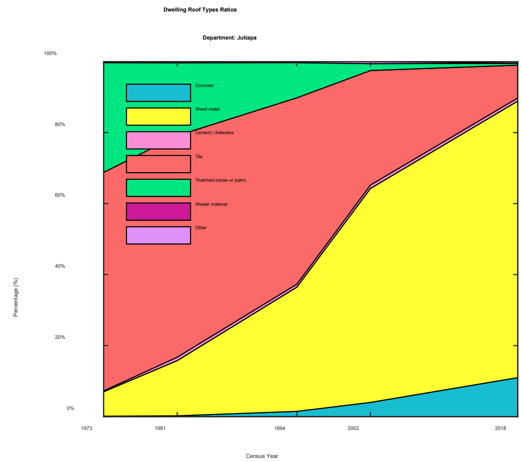

Dwelling Wall Types
Department: Jalapa
Concrete
Adobe
Wood
Bajareque
Tree bark, wood/cane sticks
Other / Wastee Material
Sheet Metal
Number of Dwellings (Thousands)
Census Year

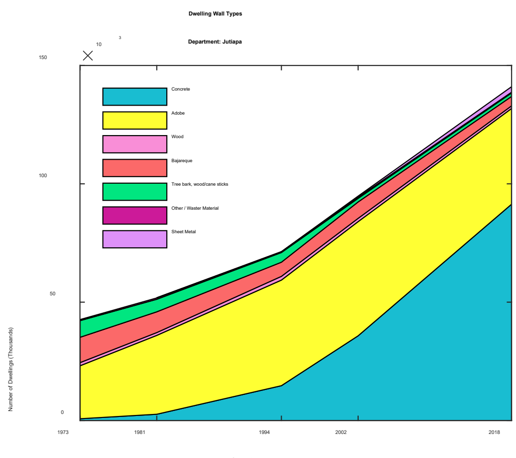

Dwelling Occupancy Condition
Department: Jalapa
Occupied
Unoccupied
Temporary use
DK/NA
Number of Dwellings (Thousands)
Census Year

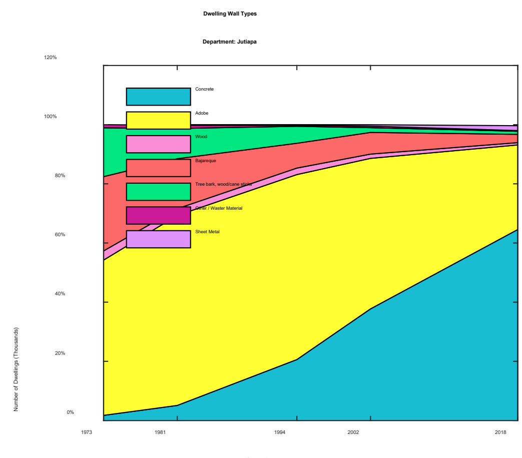

Dwelling Occupancy Condition Ratios
Department: Jalapa
Occupied
Unoccupied
Temporary use
DK/NA
Percentage (%)
Census Year

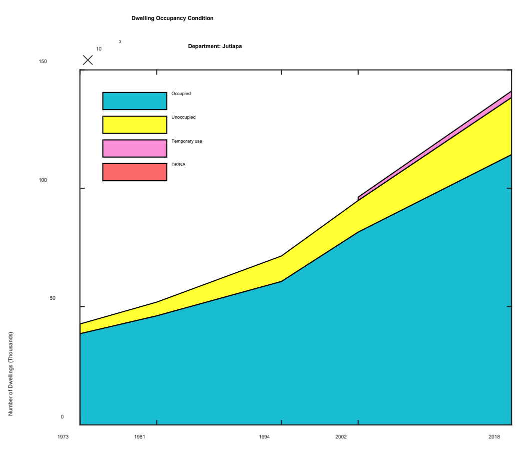
A.1.22. Jutiapa

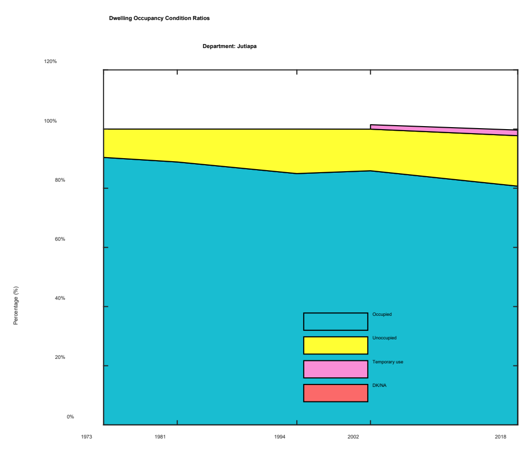






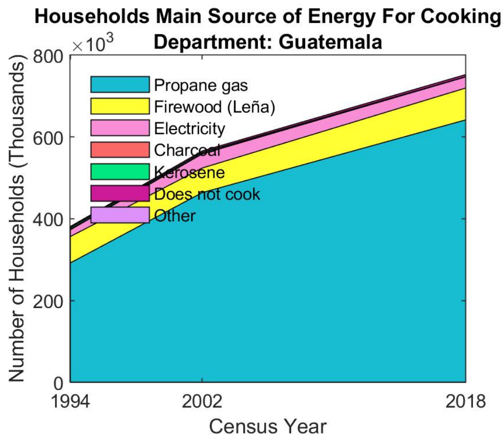


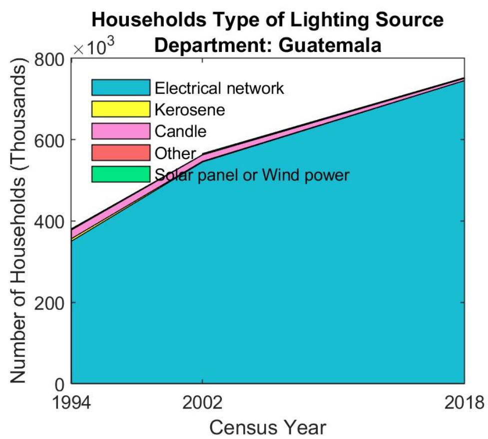


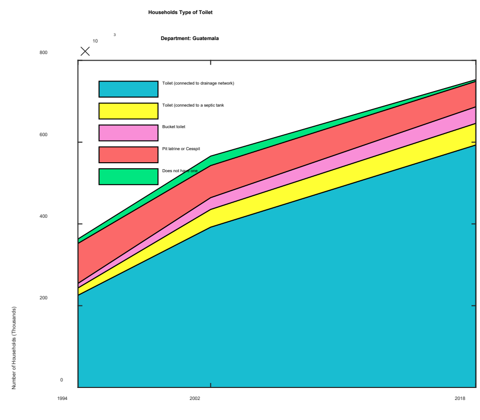


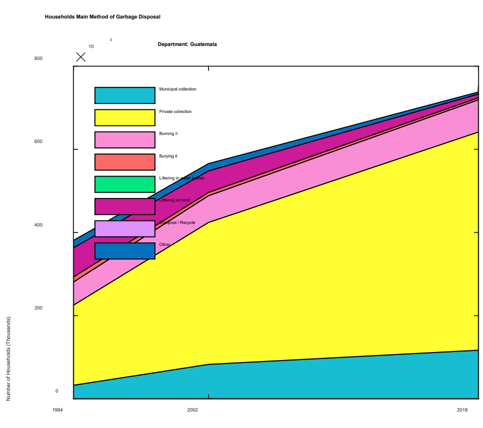
A.2. Housing utilities and services

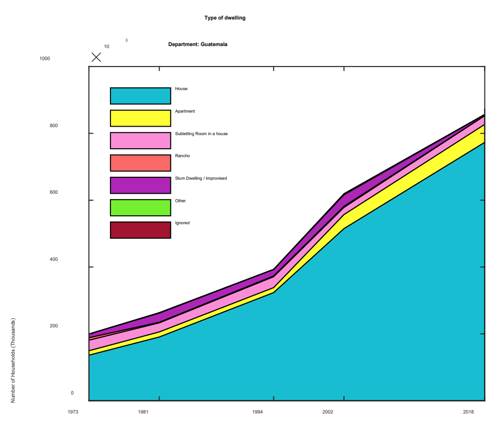
A.2.1. Department of Guatemala



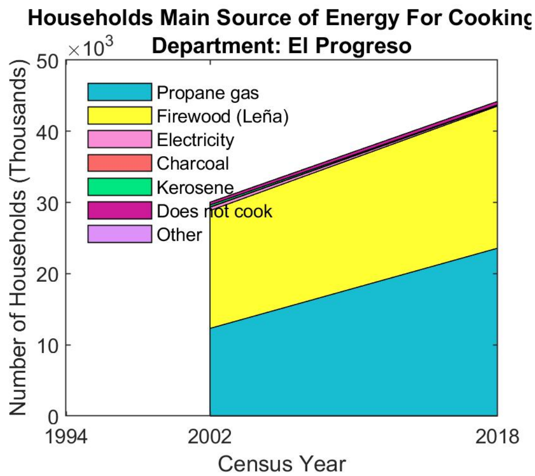


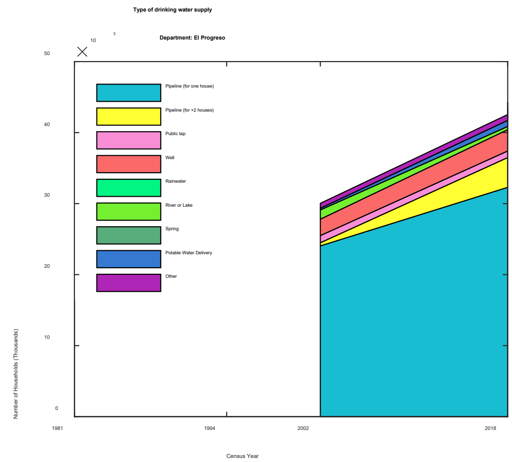


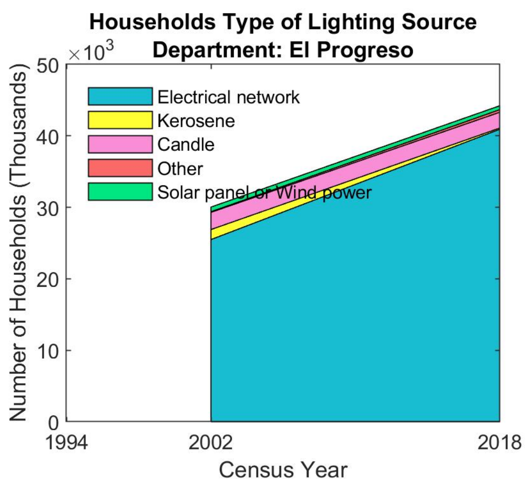


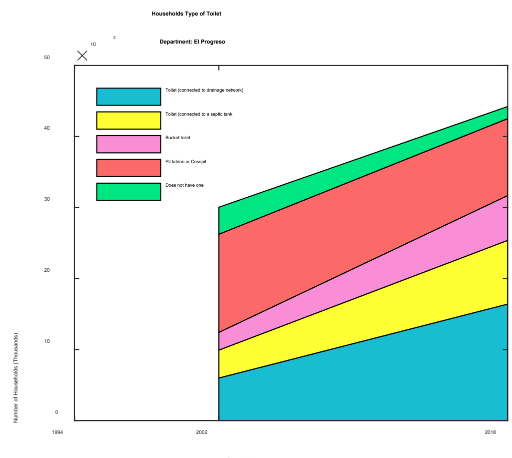


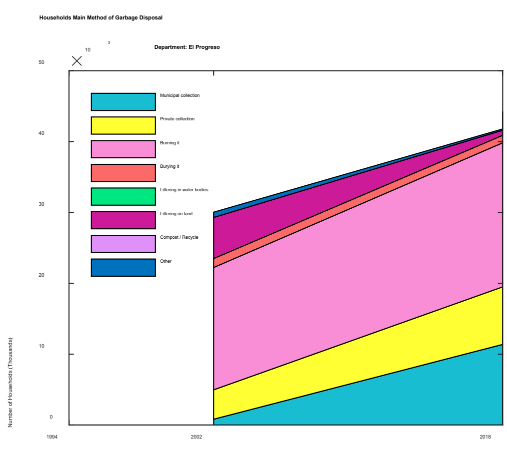
A.2.2. El Progreso

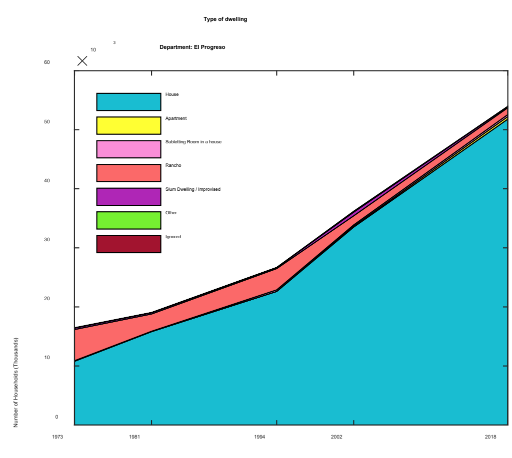




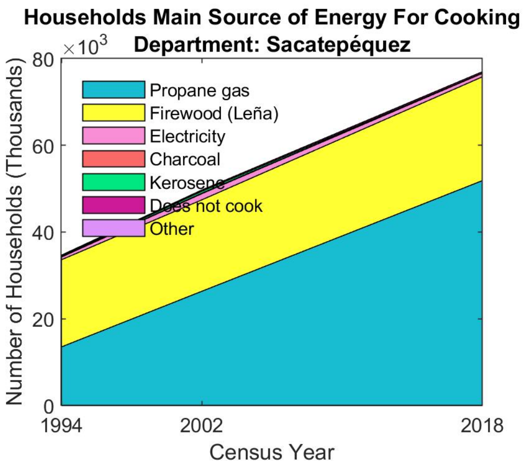


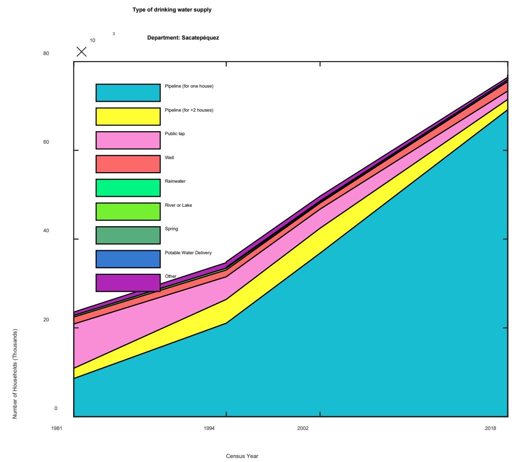


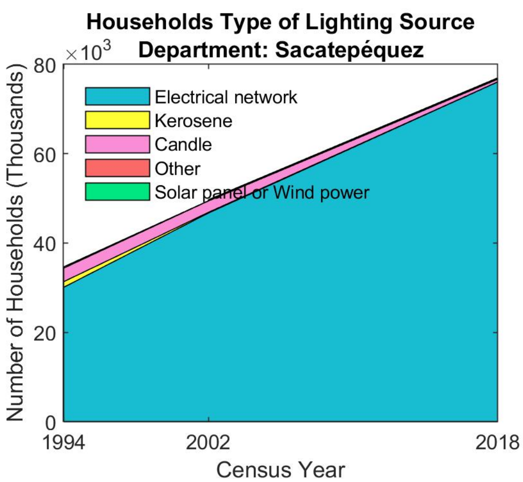


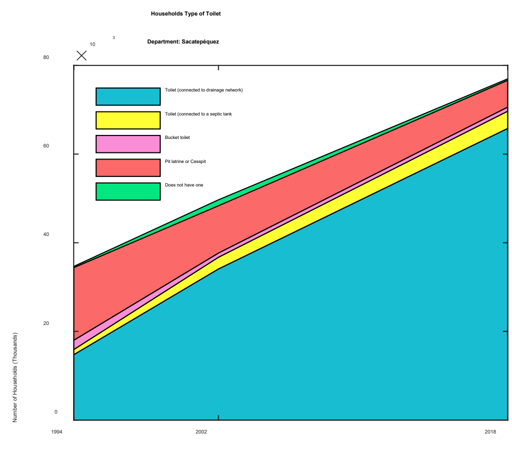


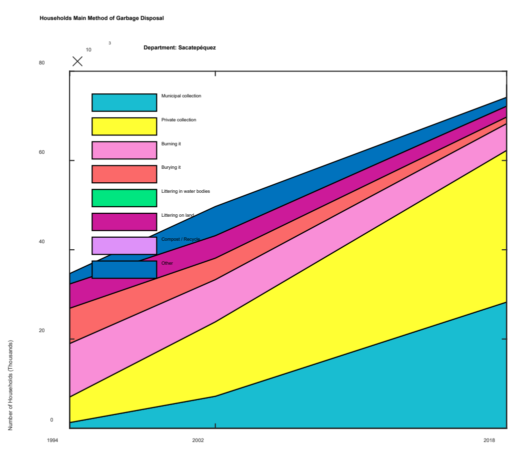
A.2.3. Sacatepéquez

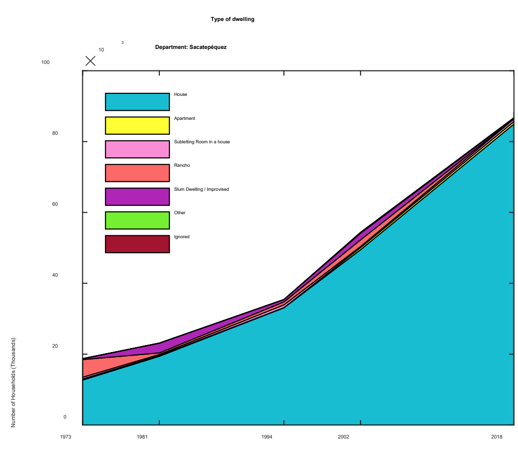




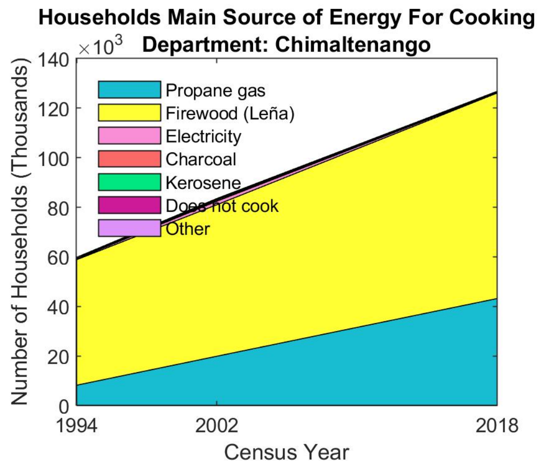


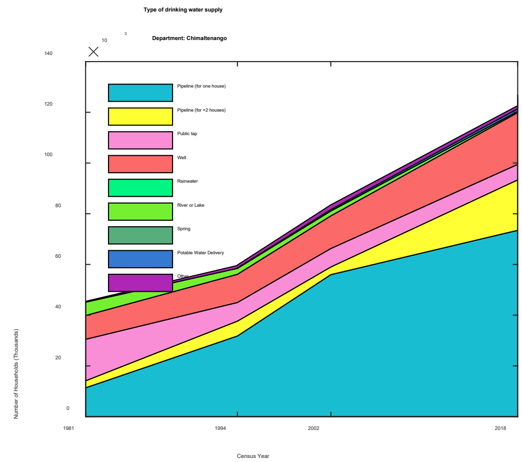


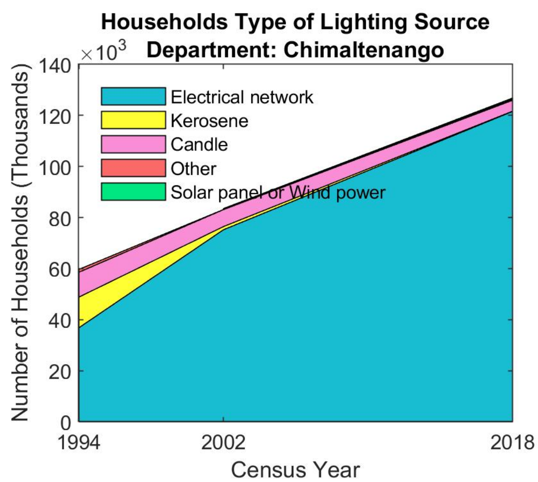


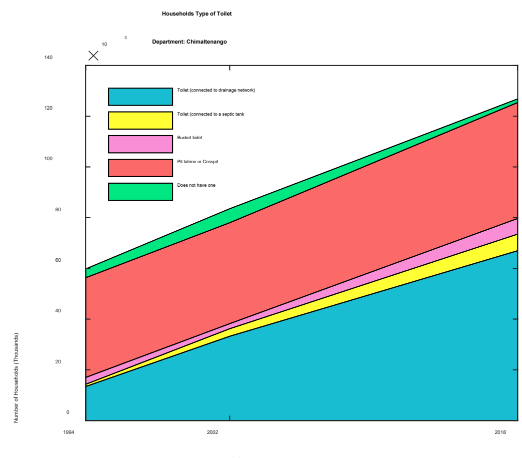


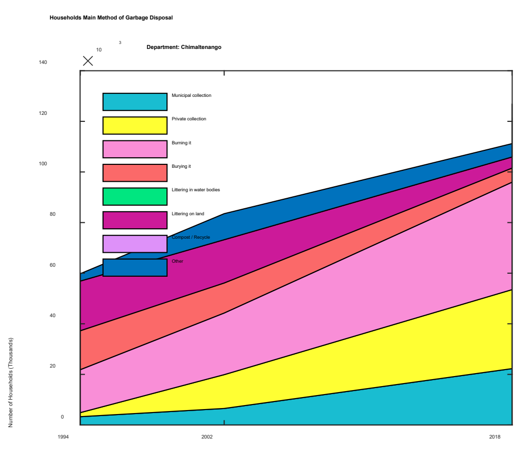
A.2.4. Chimaltenango

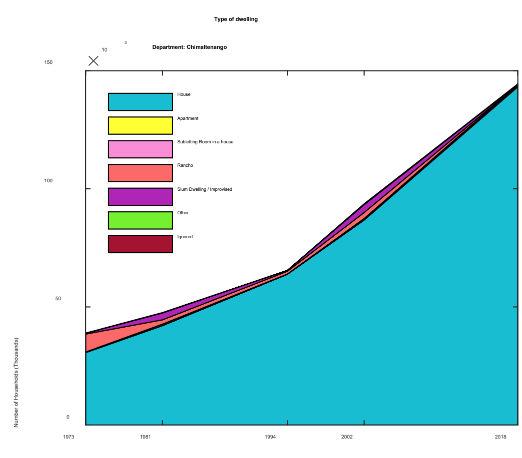




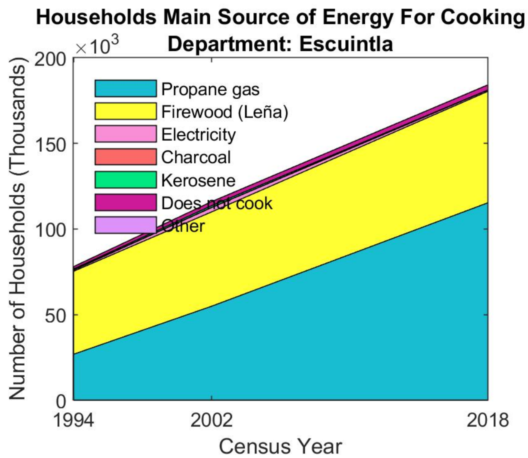


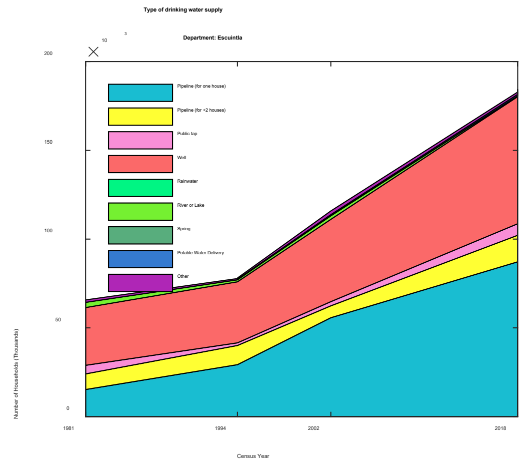


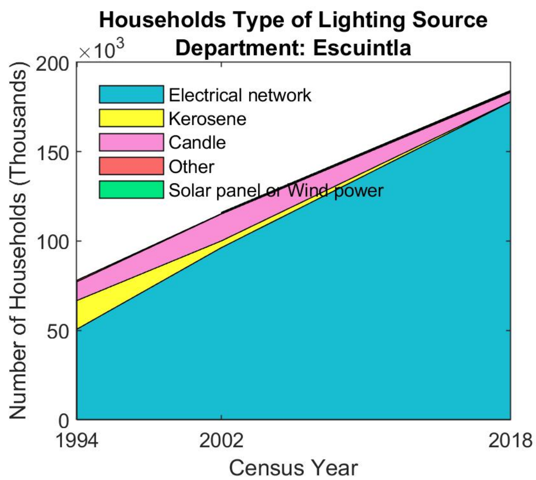


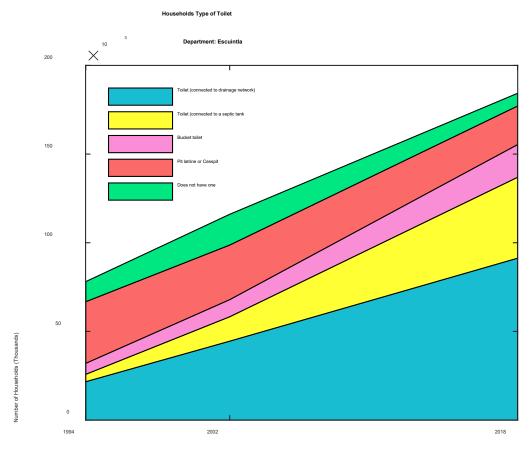


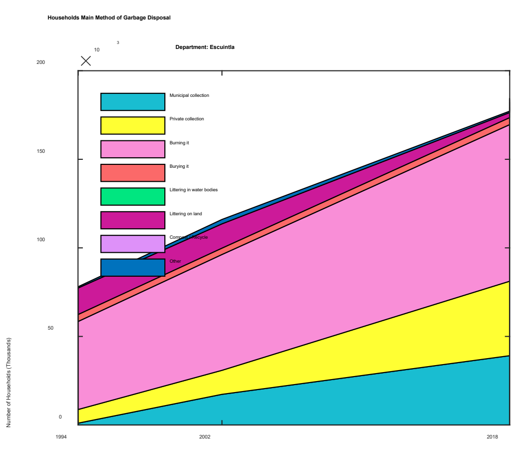
A.2.5. Escuintla

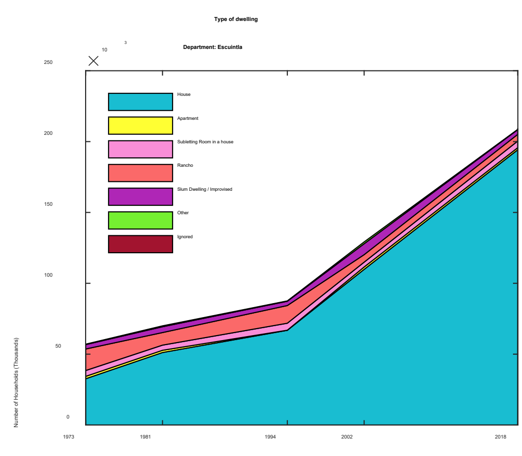




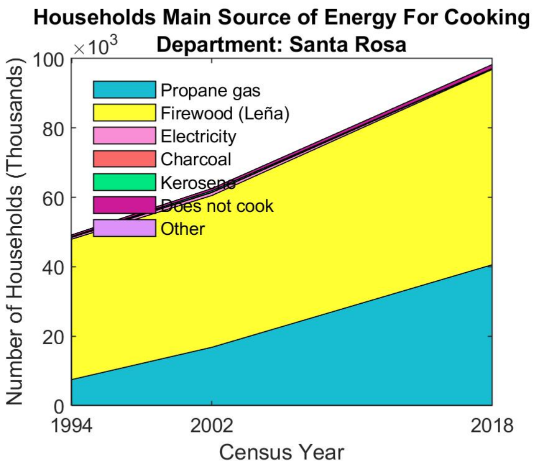


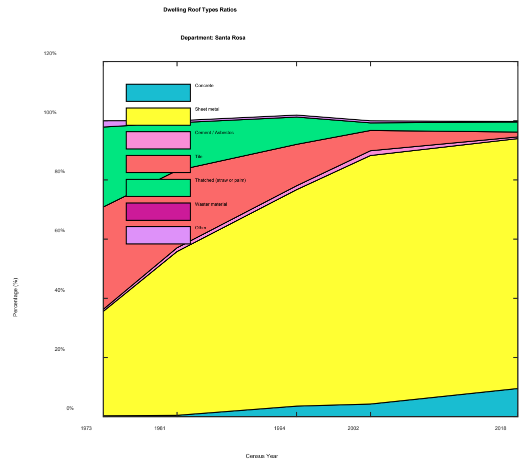


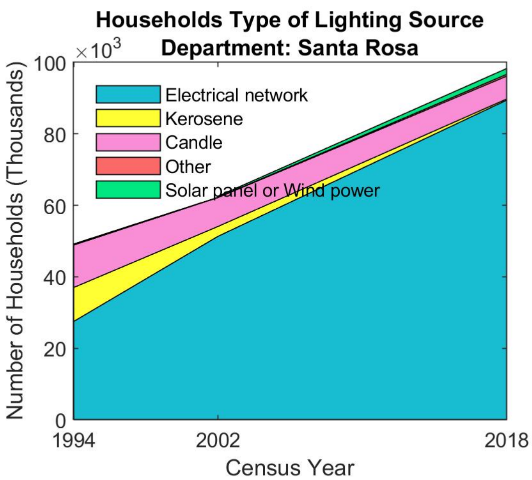


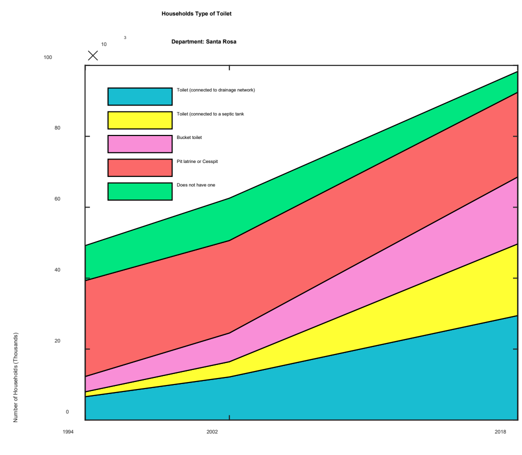


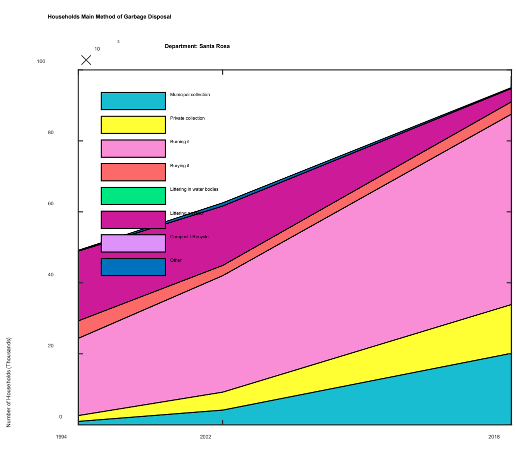
A.2.6. Santa Rosa

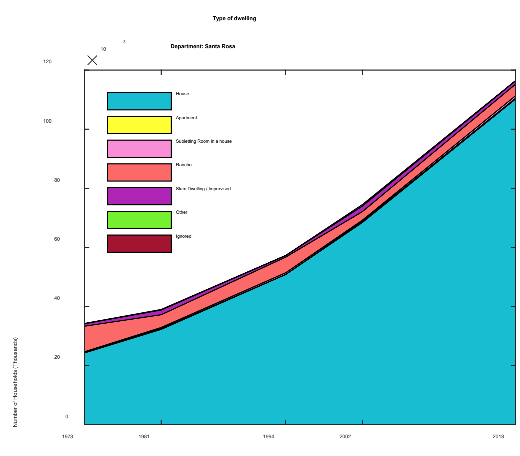




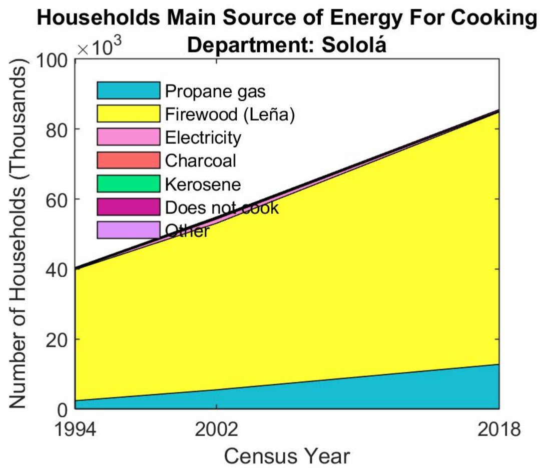


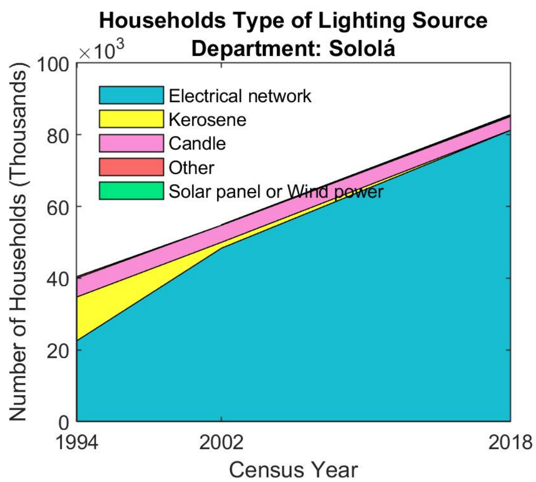


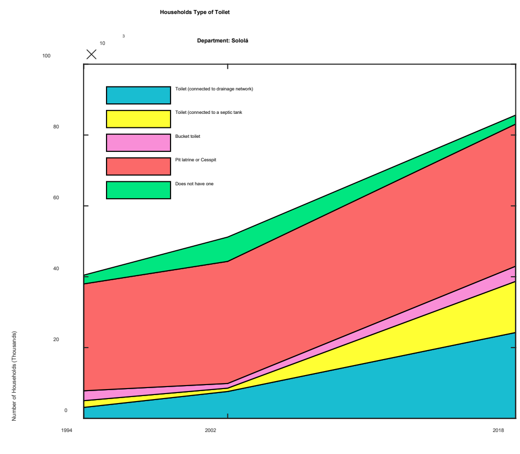


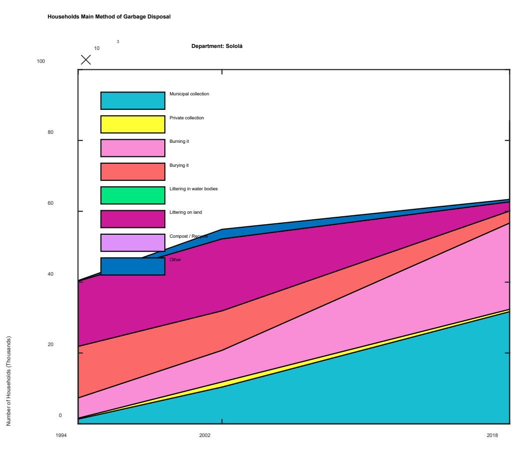


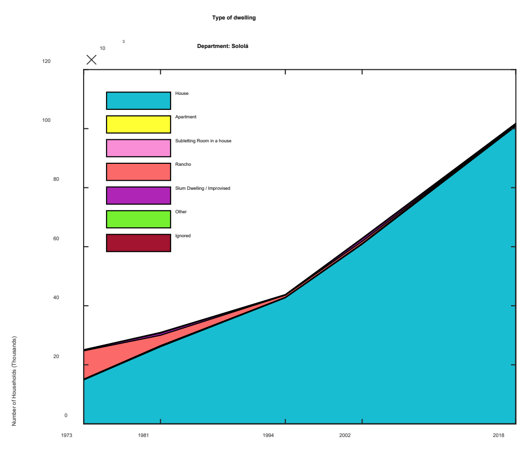
A.2.7. Sololá


Households Main Source of Energy For Cooking
Department: Sololá
Propane gas
Firewood (Leña)
Electricity
Charcoal
Kerosene
Does not cook
Other
Number of Households (Thousands)
Census Year

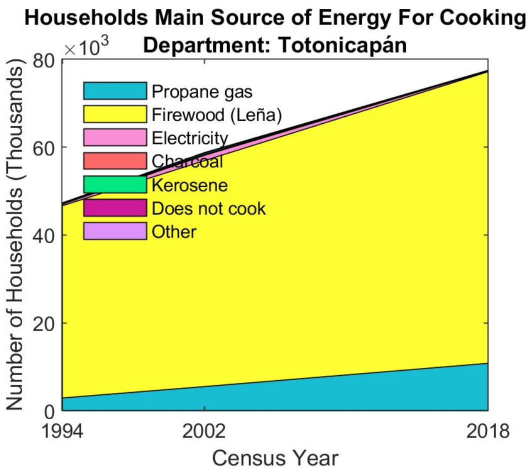

Households Type of Lighting Source
Department: Sololá
Electrical network
Kerosene
Candle
Other
Solar panel or Wind power
Number of Households (Thousands)
Census Year

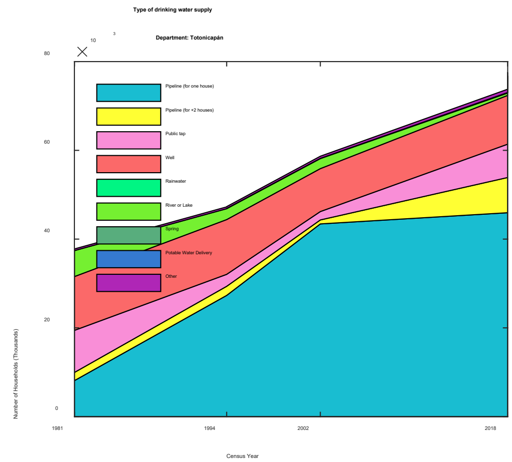

Households Type of Toilet
Department: Sololá
Toilet (connected to drainage network)
Toilet (connected to a septic tank
Bucket toilet
Pit latrine or Cesspit
Does not have one
Number of Households (Thousands)
Census Year

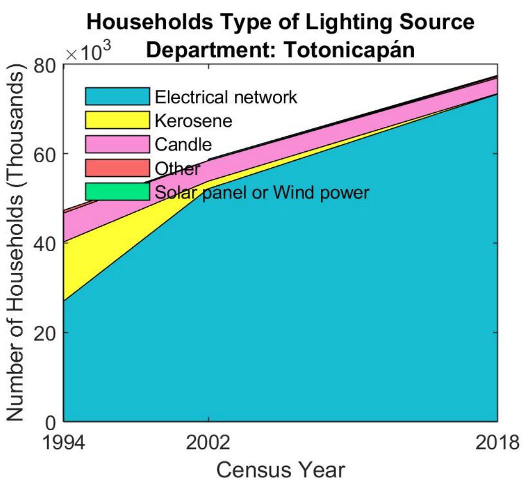

Households Main Method of Garbage Disposal
Department: Sololá
Municipal collection
Private collection
Burning it
Burying it
Littering in water bodies
Littering on land
Compost / Recycle
Other
Number of Households (Thousands)
Census Year

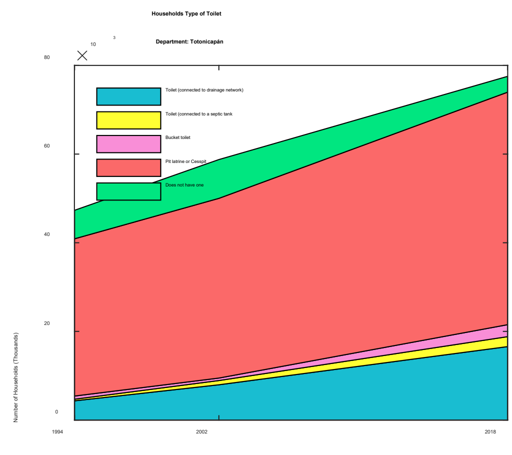

Type of dwelling
Department: Sololá
House
Apartment
Subletting Room in a house
Rancho
Slum Dwelling / Improvised
Other
Ignored
Number of Households (Thousands)
Census Year

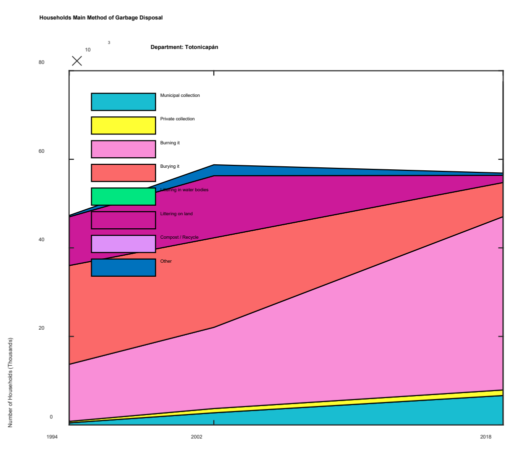
A.2.8. Totonicapán

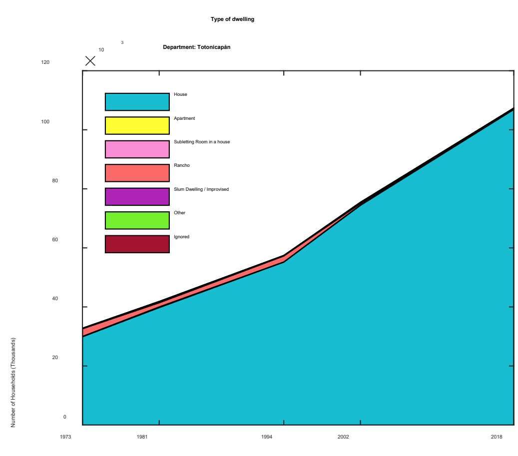




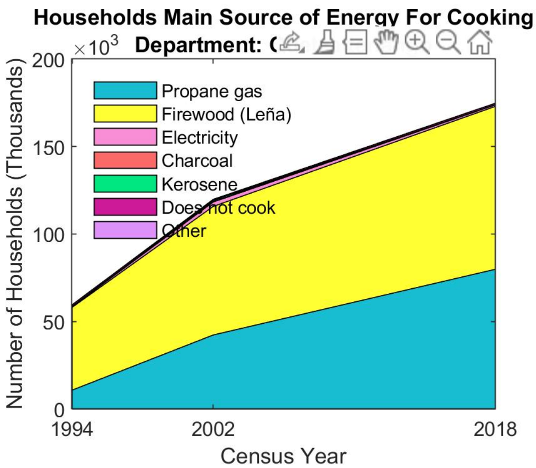


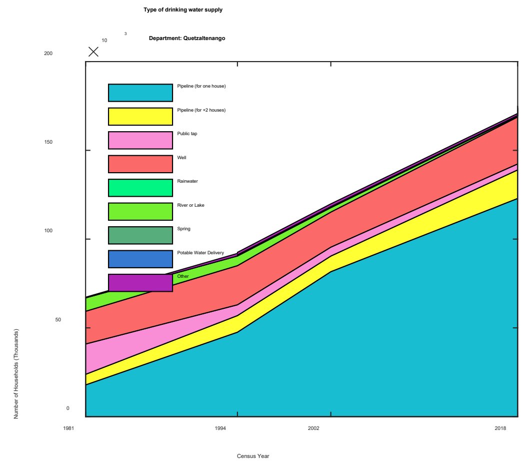


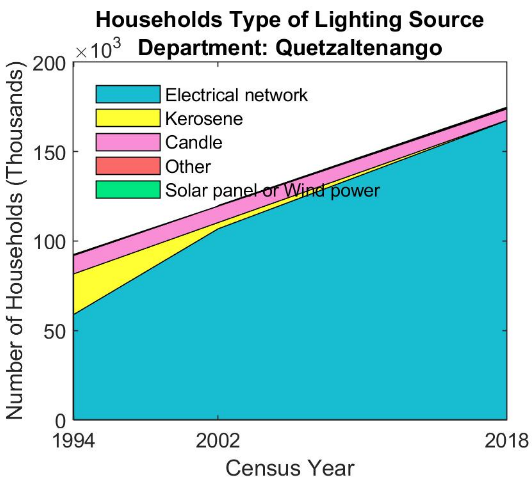


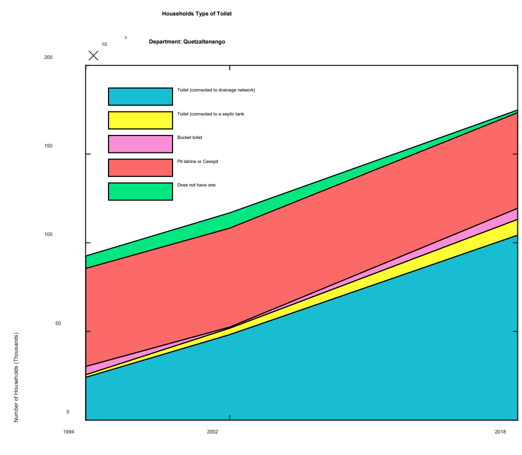


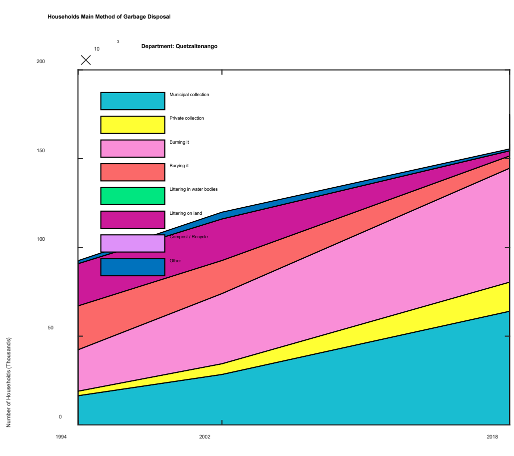
A.2.9. Quetzaltenango

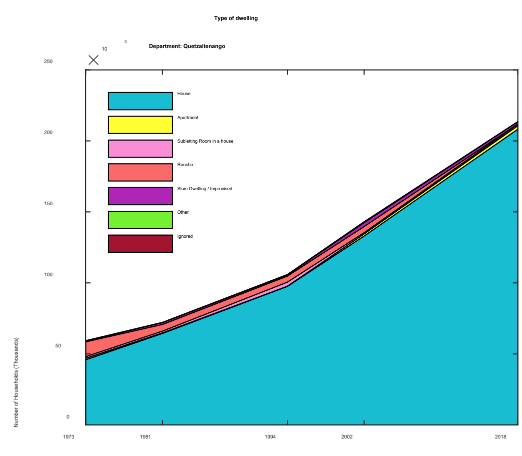




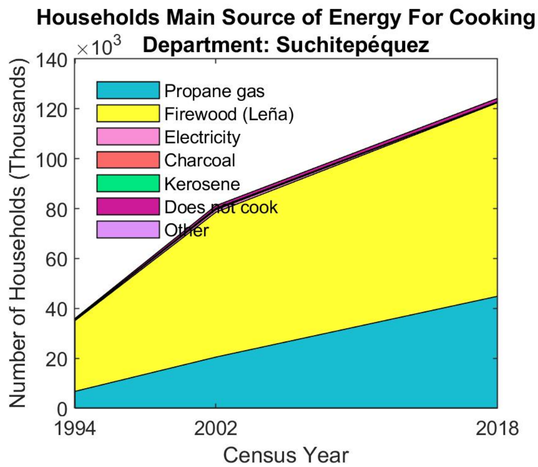


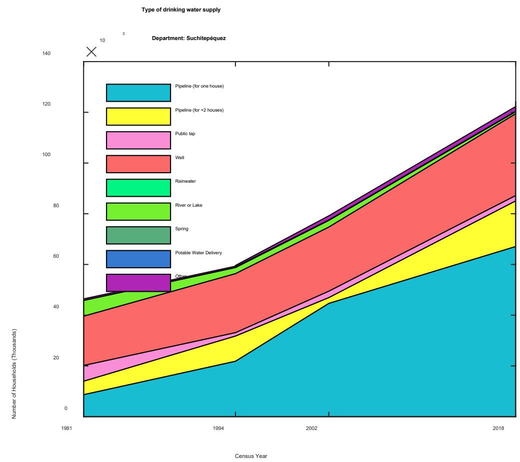


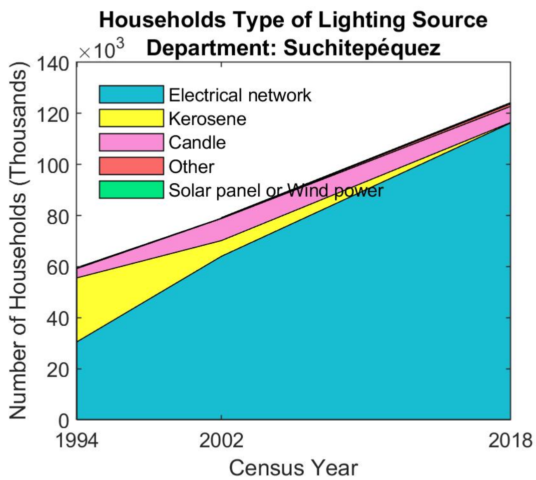


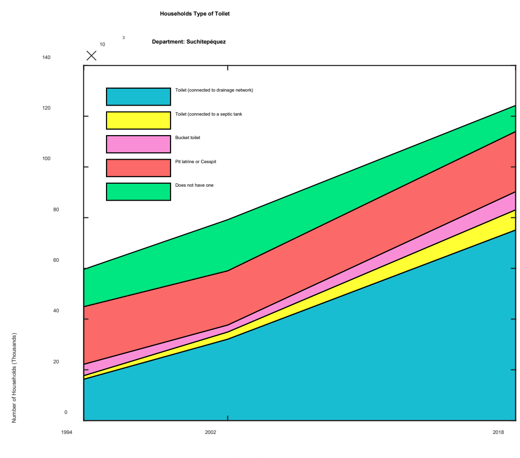


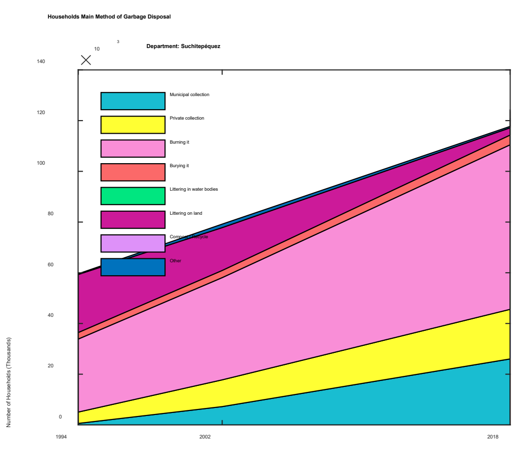
A.2.10. Suchitepequez

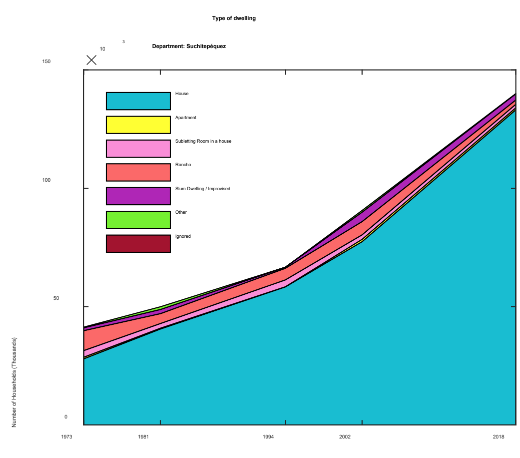




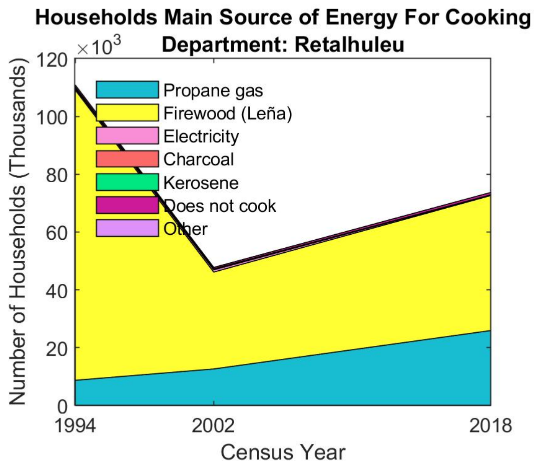


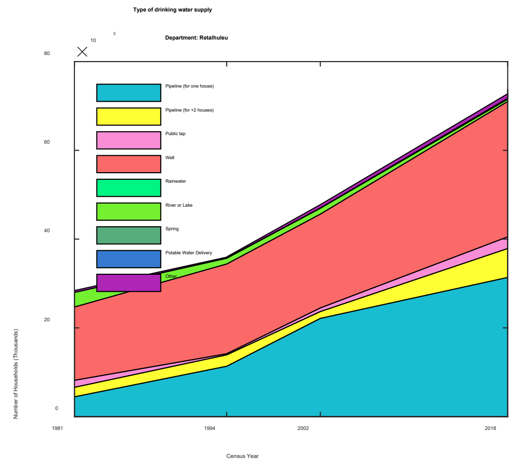


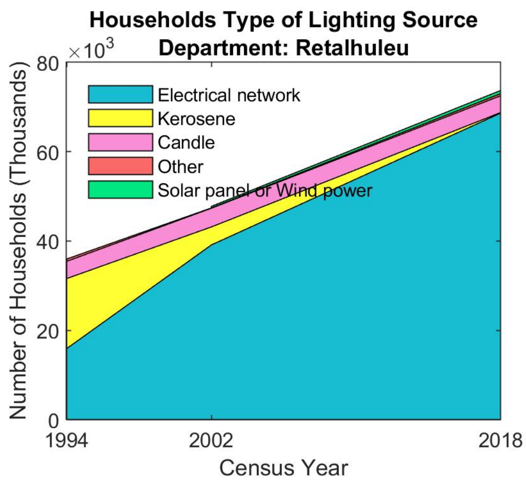


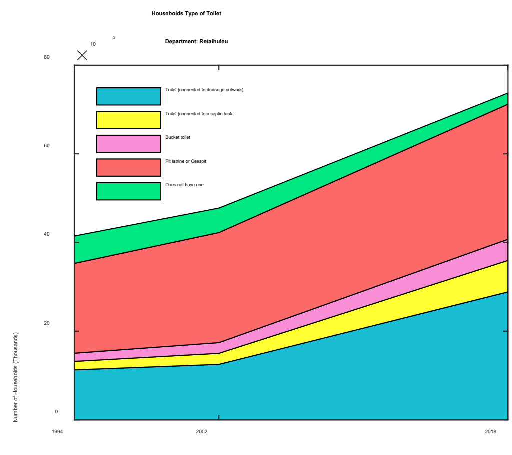


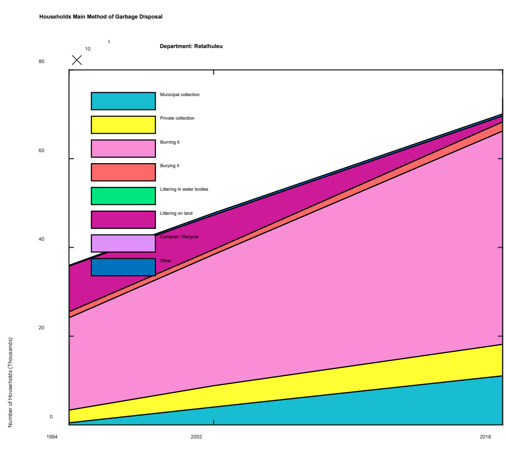
A.2.11. Retalhuleu

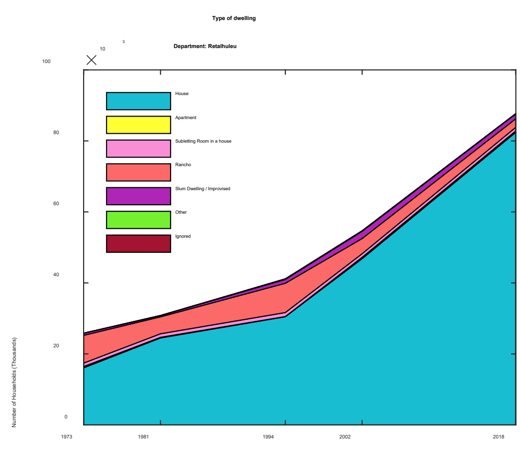




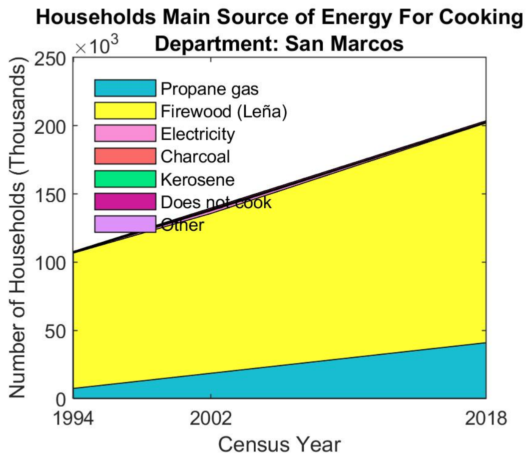


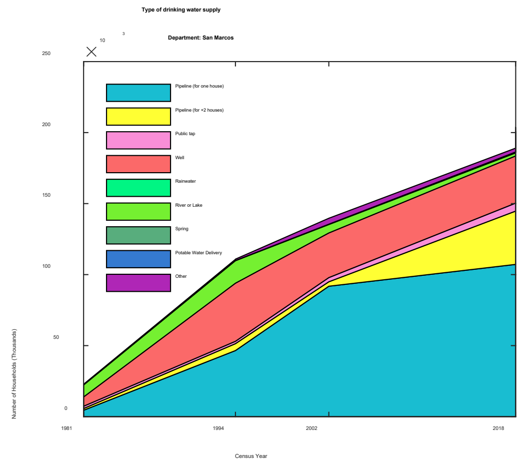


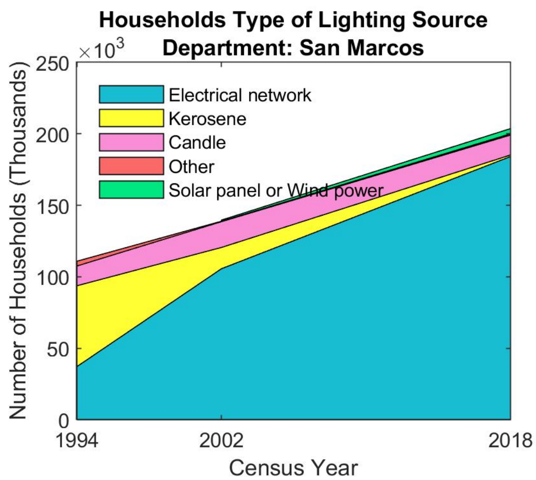


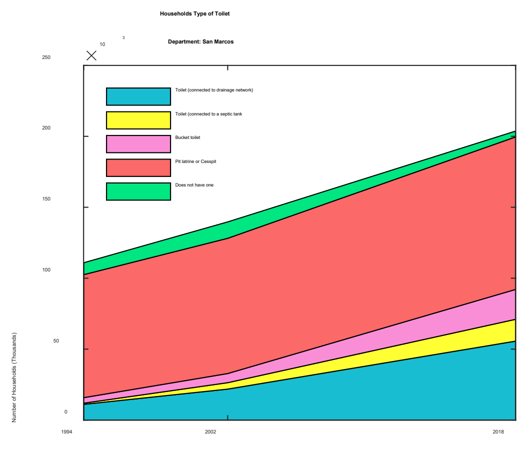


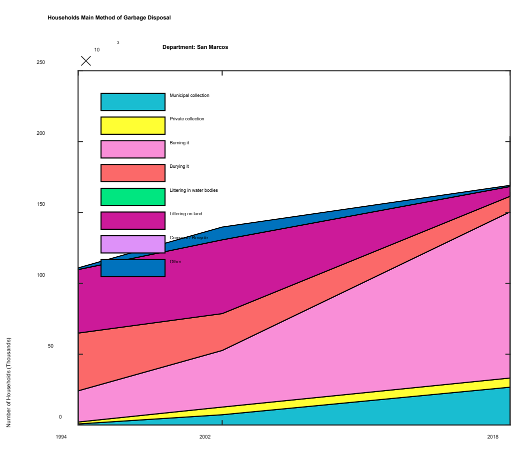
A.2.12. San Marcos

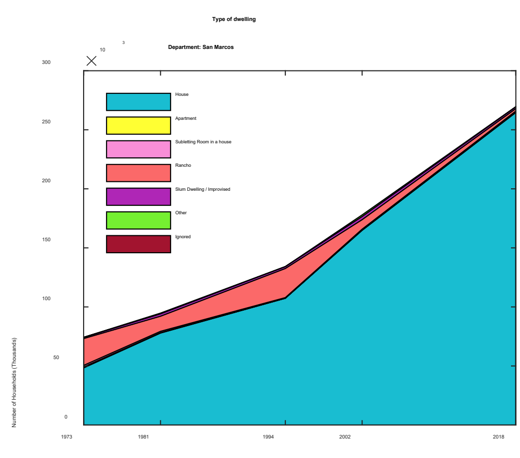




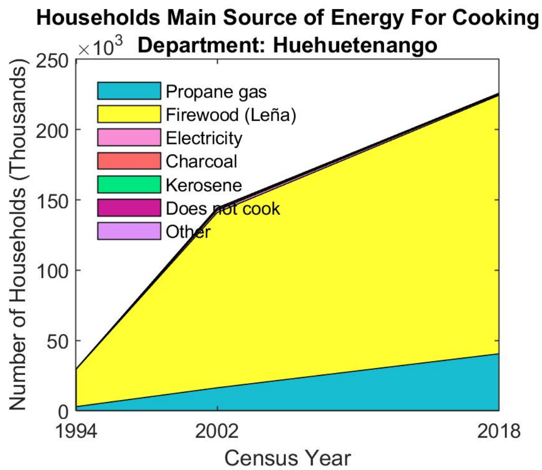


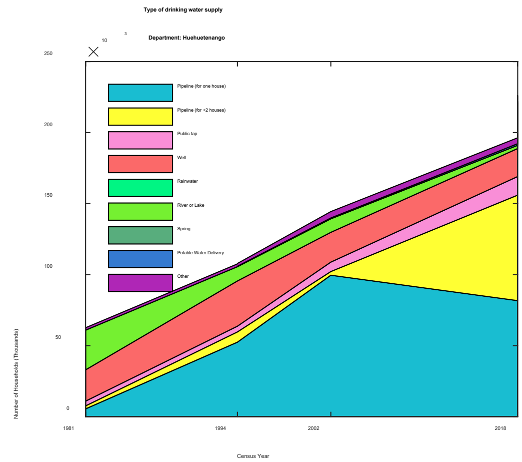


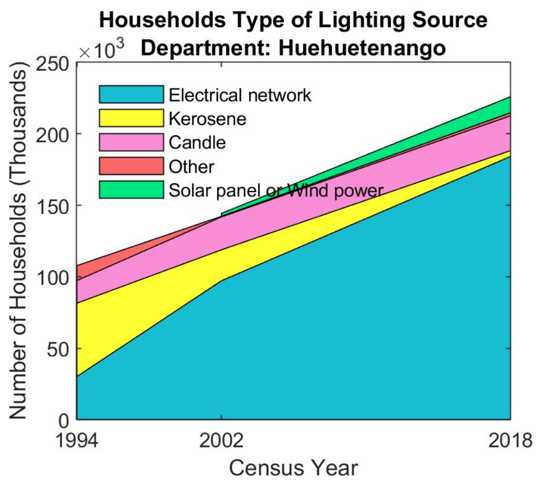


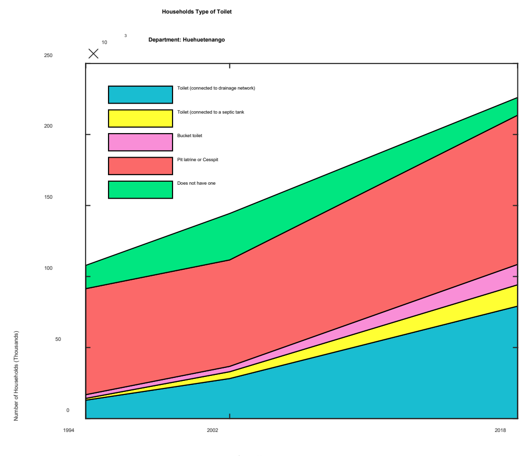


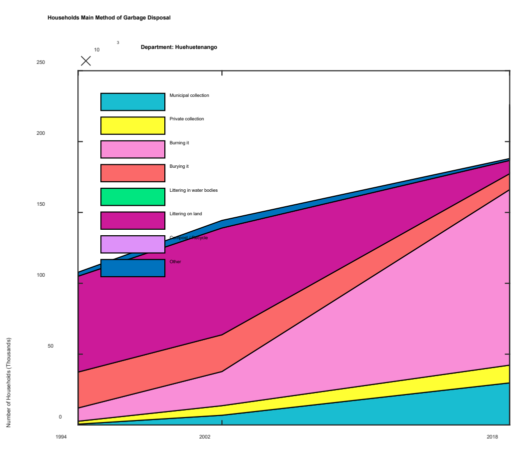
A.2.13. Huehuetenango

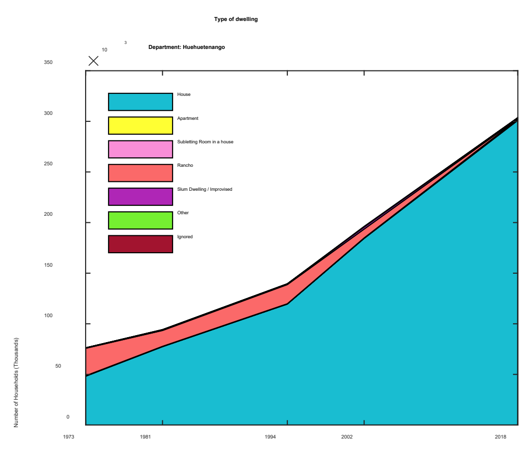




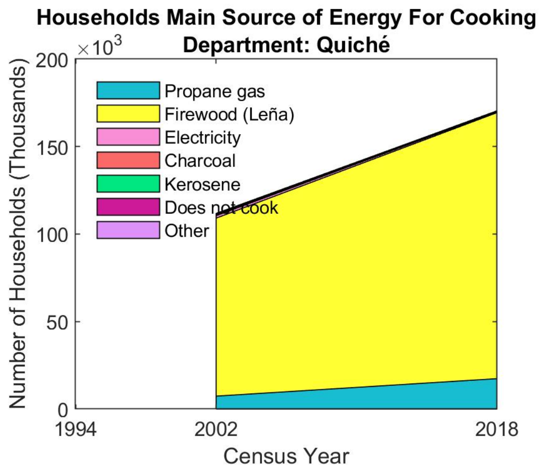


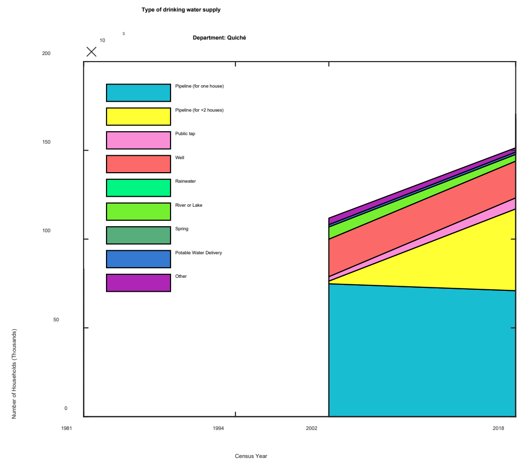


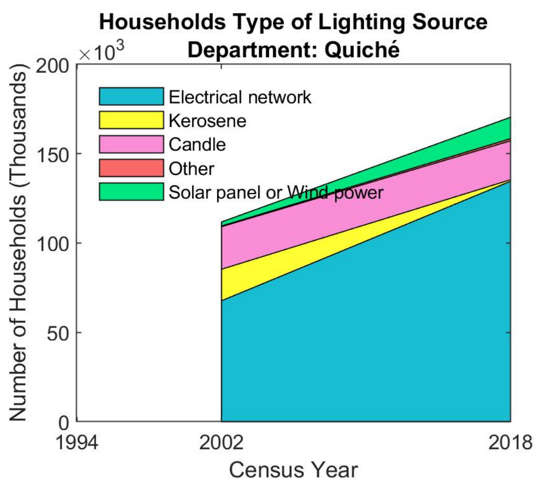


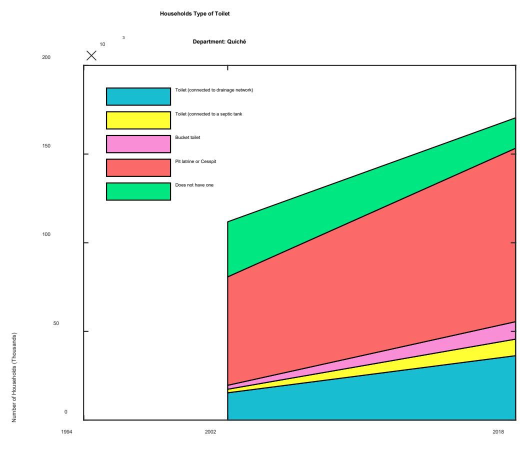


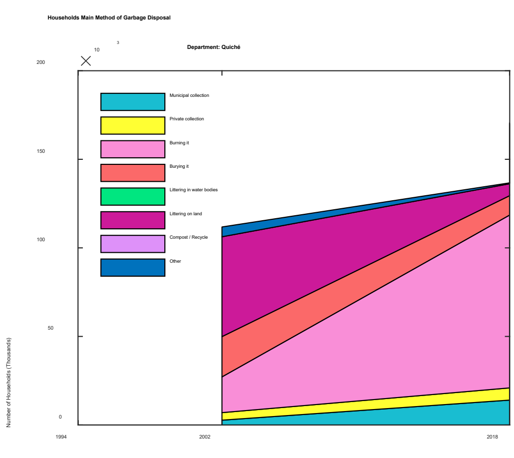
A.2.14. Quiché

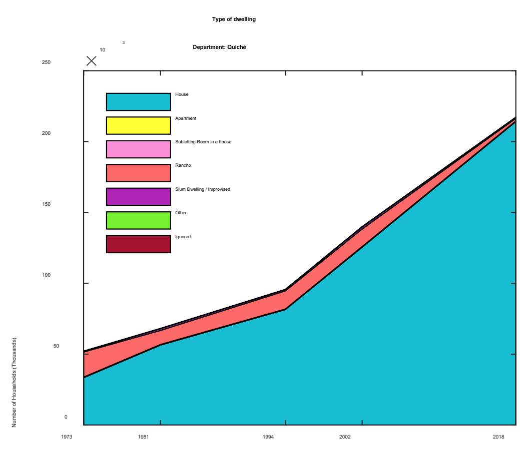

Households Main Source of Energy For Cooking
Department: Quiché
Propane gas
Firewood (Leña)
Electricity
Charcoal
Kerosene
Does not cook
Other
Number of Households (Thousands)
Census Year


Type of drinking water supply
Department: Quiché
Pipeline (for one house)
Pipeline (for +2 houses)
Public tap
Well
Rainwater
River or Lake
Spring
Potable Water Delivery
Other
Number of Households (Thousands)
Census Year

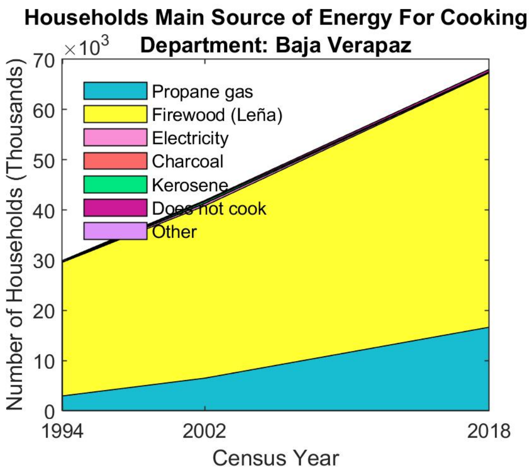

Households Type of Lighting Source
Department: Quiché
Electrical network
Kerosene
Candle
Other
Solar panel or Wind power
Number of Households (Thousands)
Census Year

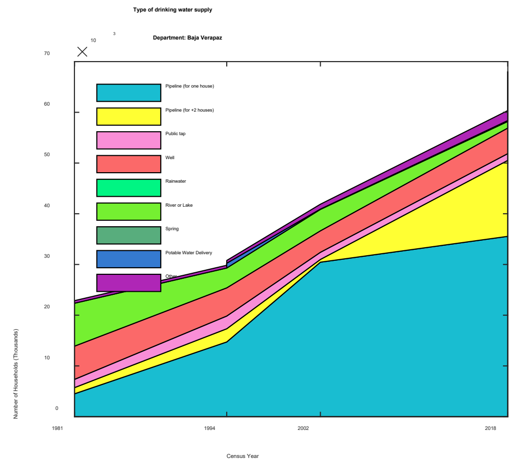

Households Type of Toilet
Department: Quiché
Toilet (connected to drainage network)
Toilet (connected to a septic tank
Bucket toilet
Pit latrine or Cesspit
Does not have one
Number of Households (Thousands)
Census Year

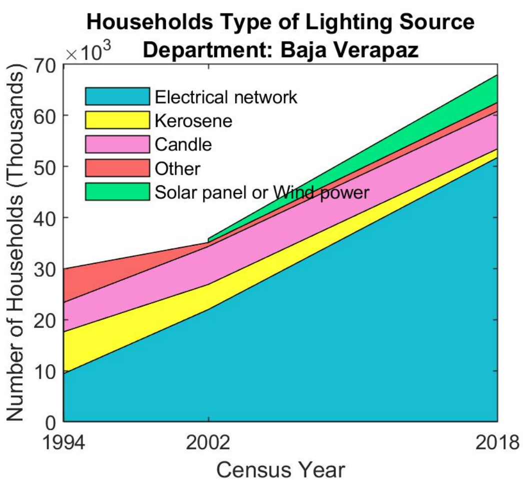

Households Main Method of Garbage Disposal
Department: Quiché
Municipal collection
Private collection
Burning it
Burying it
Littering in water bodies
Littering on land
Compost / Recycle
Other
Number of Households (Thousands)
Census Year

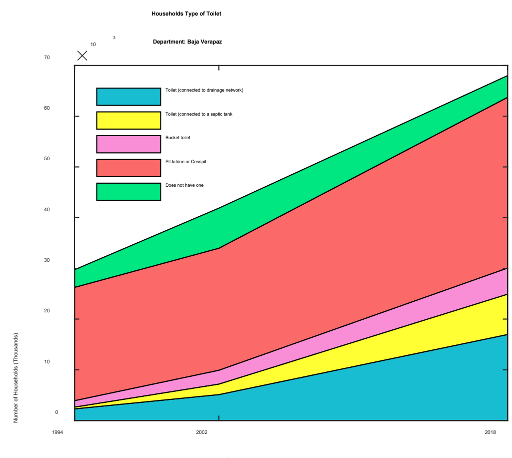

Type of dwelling
Department: Quiché
House
Apartment
Subletting Room in a house
Rancho
Slum Dwelling / Improvised
Other
Ignored
Number of Households (Thousands)
Census Year

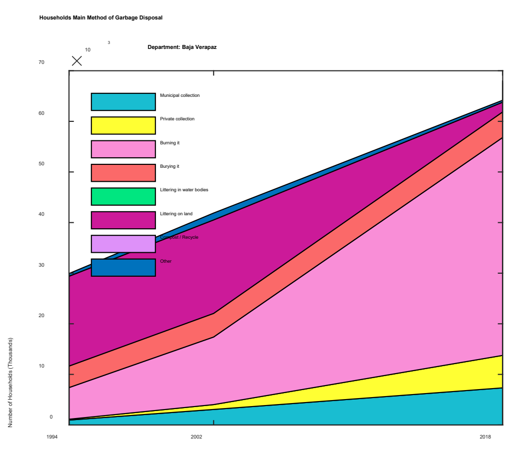
A.2.15. Baja Verapaz

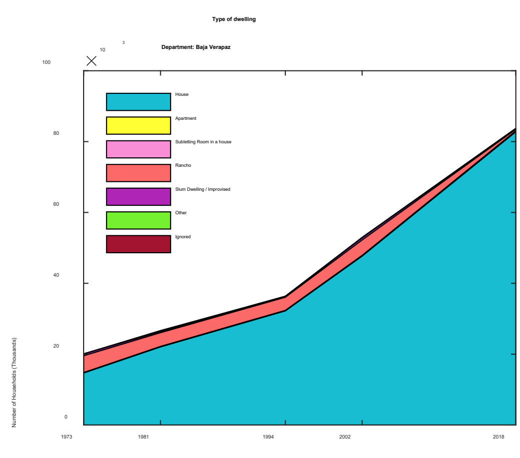




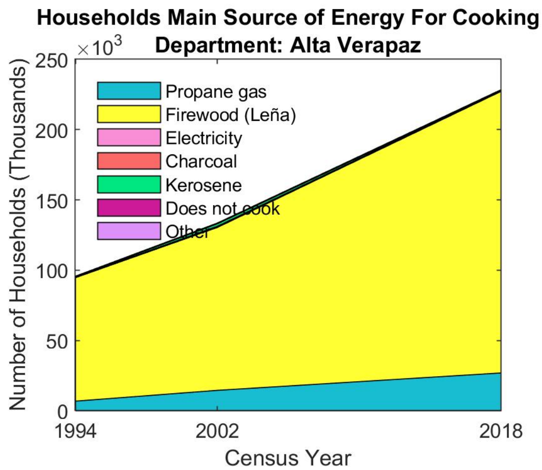


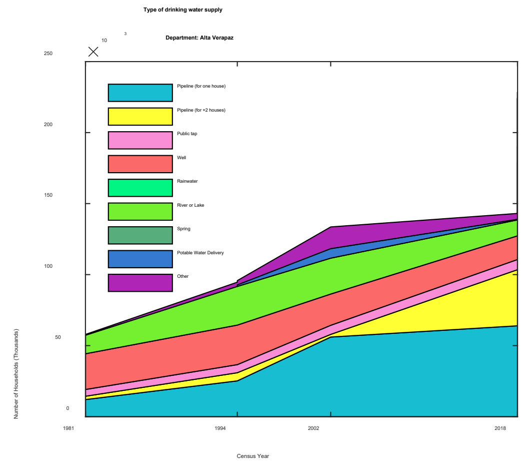


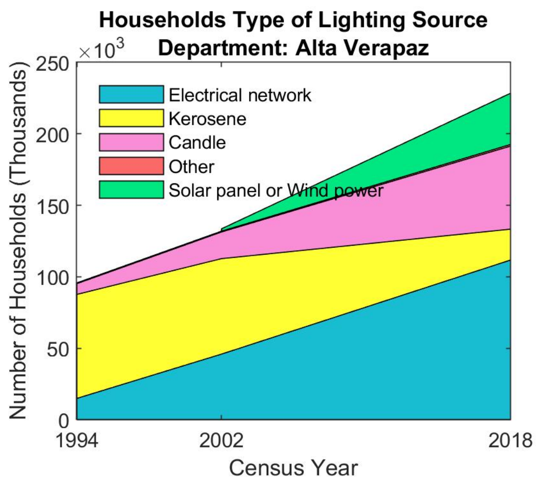


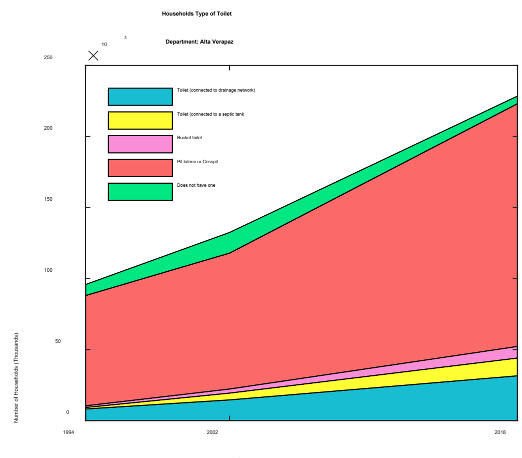


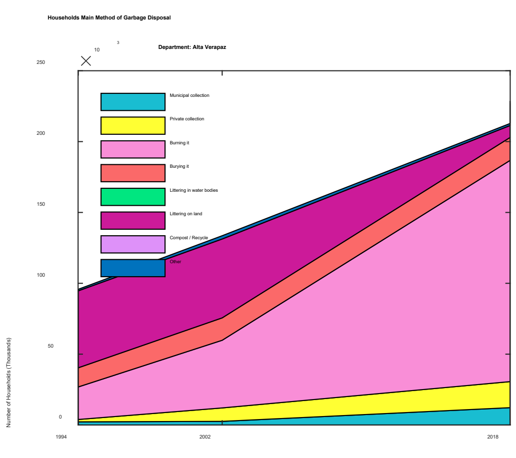
A.2.16. Alta Verapaz

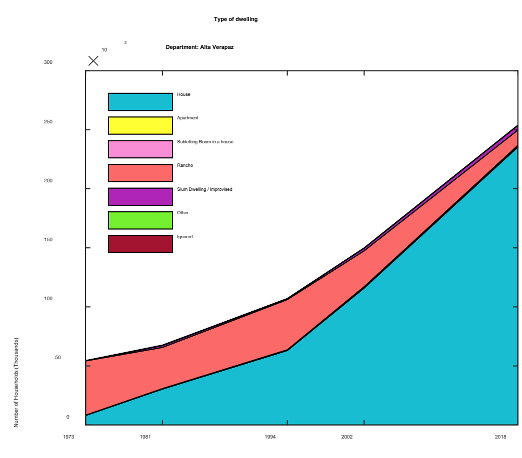




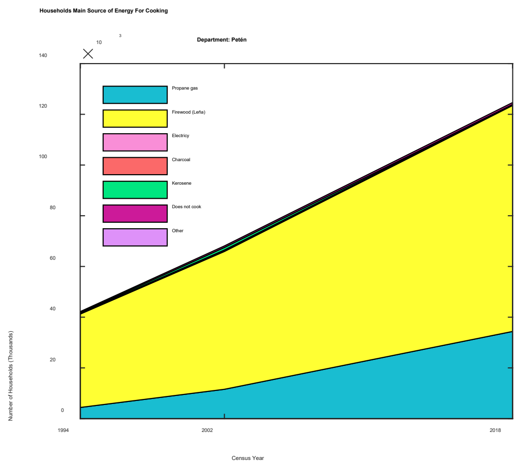




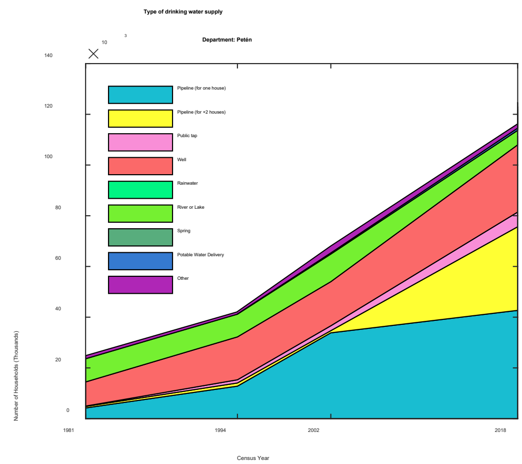




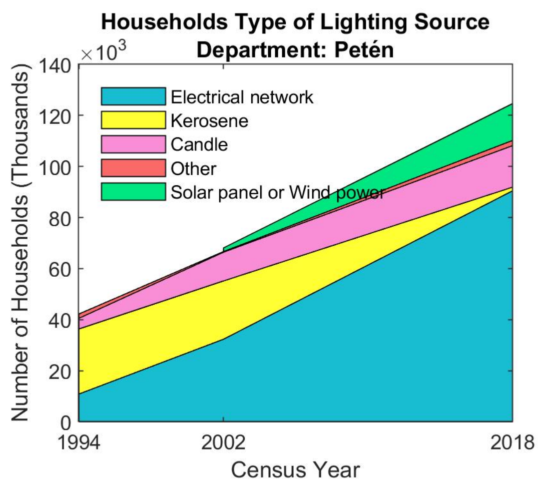
A.2.17. Petén



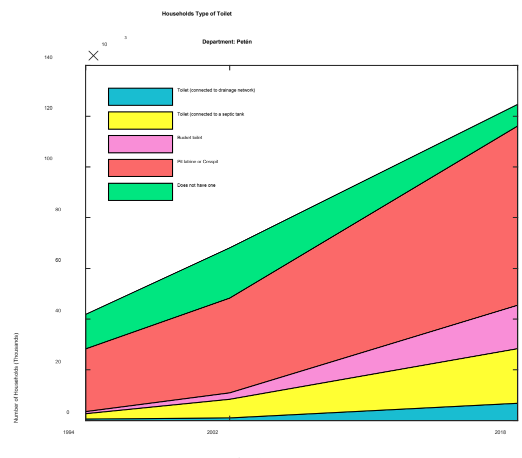
Households Main Source of Energy For Cooking
Department: Petén
Propane gas
Firewood (Leña)
Electricy
Charcoal
Kerosene
Does not cook
Other
Number of Households (Thousands)
Census Year



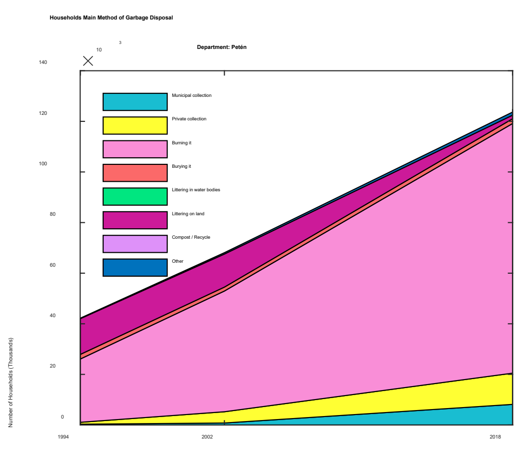
Type of drinking water supply
Department: Petén
Pipeline (for one house)
Pipeline (for +2 houses)
Public tap
Well
Rainwater
River or Lake
Spring
Potable Water Delivery
Other
Number of Households (Thousands)
Census Year



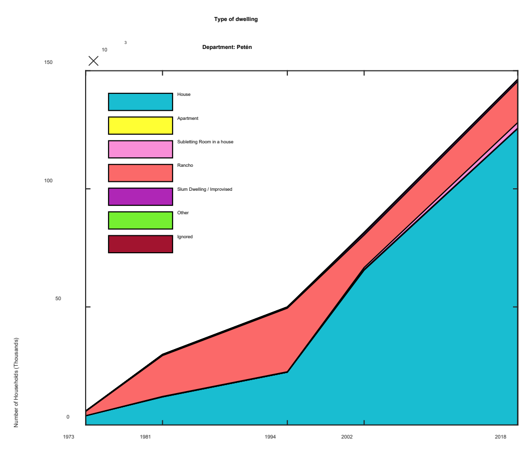
Households Type of Lighting Source
Department: Petén
Electrical network
Kerosene
Candle
Other
Solar panel or Wind power
Number of Households (Thousands)
Census Year



Households Type of Toilet
Department: Petén
Toilet (connected to drainage network)
Toilet (connected to a septic tank
Bucket toilet
Pit latrine or Cesspit
Does not have one
Number of Households (Thousands)
Census Year

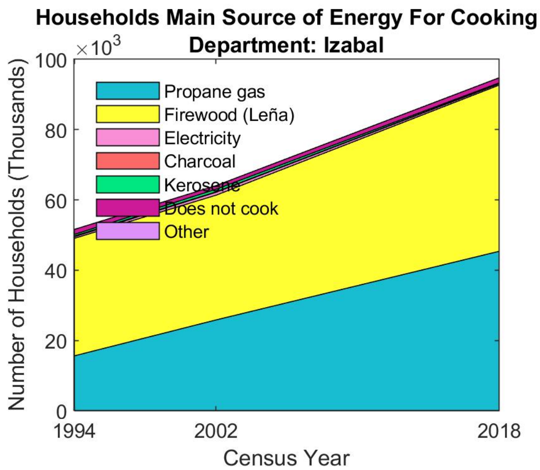


Households Main Method of Garbage Disposal
Department: Petén
Municipal collection
Private collection
Burning it
Burying it
Littering in water bodies
Littering on land
Compost / Recycle
Other
Number of Households (Thousands)
Census Year

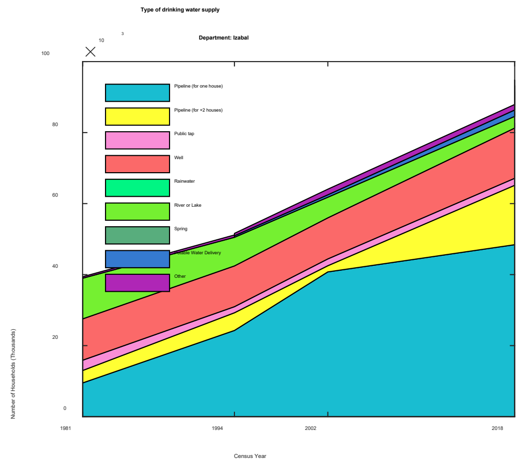


Type of dwelling
Department: Petén
House
Apartment
Subletting Room in a house
Rancho
Slum Dwelling / Improvised
Other
Ignored
Number of Households (Thousands)
Census Year

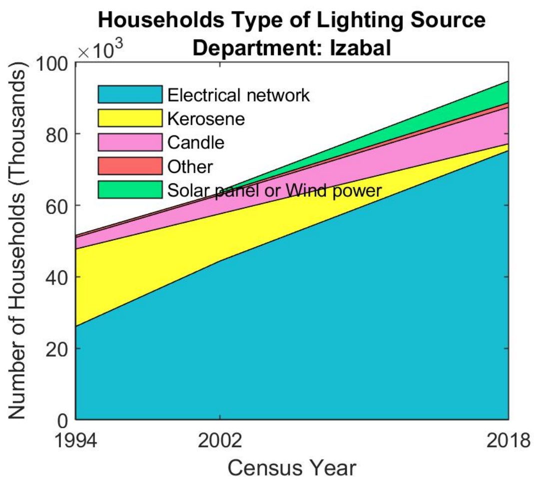
A.2.18. Izabal



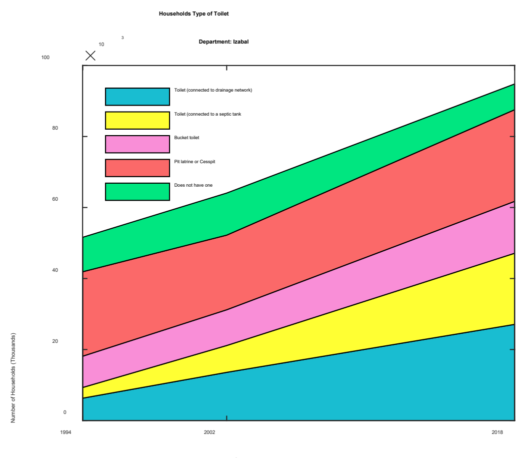
Households Main Source of Energy For Cooking
Department: Izabal
×10^3
Propane gas
Firewood (Leña)
Electricity
Charcoal
Kerosene
Does not cook
Other
Number of Households (Thousands)
Census Year



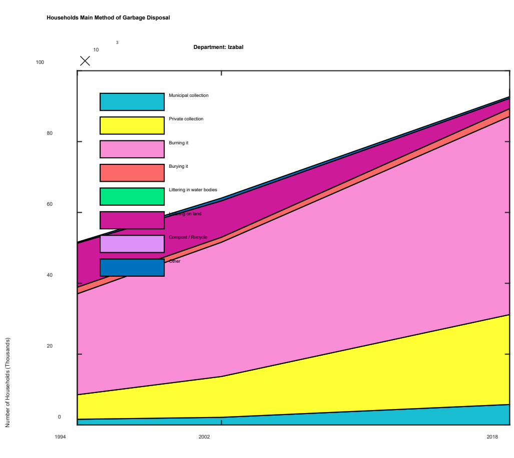
Type of drinking water supply
Department: Izabal
Pipeline (for one house)
Pipeline (for +2 houses)
Public tap
Well
Rainwater
River or Lake
Spring
Other
Number of Households (Thousands)
Census Year



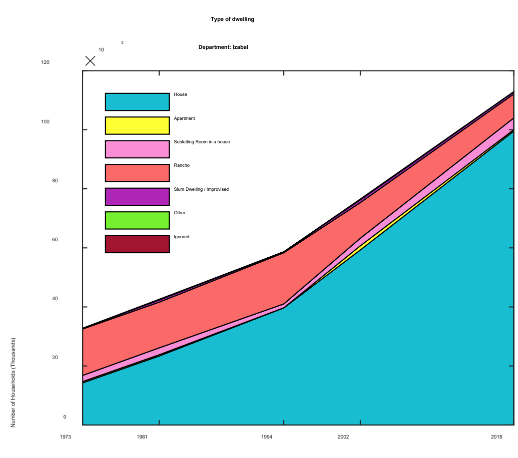
Households Type of Lighting Source
Department: Izabal
×10^3
Electrical network
Kerosene
Candle
Other
Solar panel or Wind power
Number of Households (Thousands)
Census Year



Households Type of Toilet
Department: Izabal
Toilet (connected to drainage network)
Toilet (connected to a septic tank
Bucket toilet
Pit latrine or Cesspit
Does not have one
Number of Households (Thousands)
Census Year

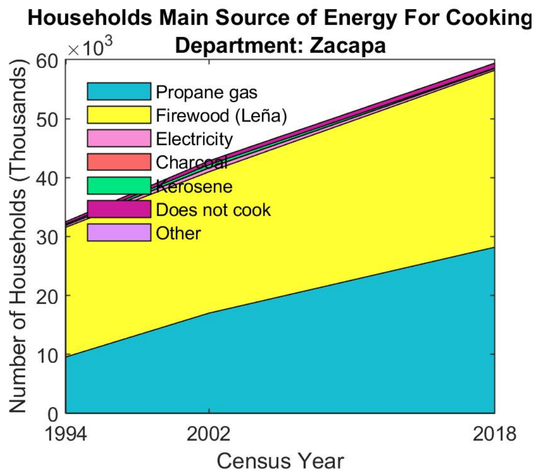


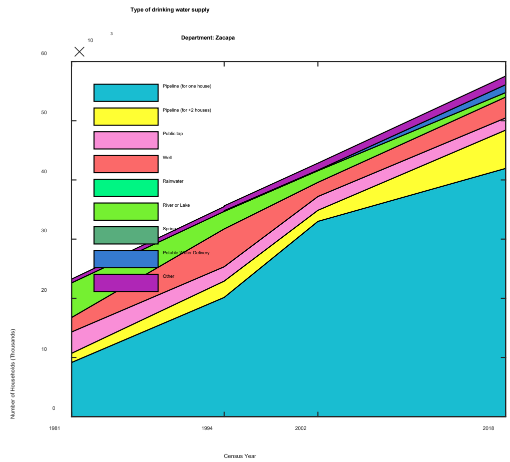
Households Main Method of Garbage Disposal
Department: Izabal
Municipal collection
Private collection
Burning it
Burying it
Littering in water bodies
Number of Households (Thousands)
Census Year

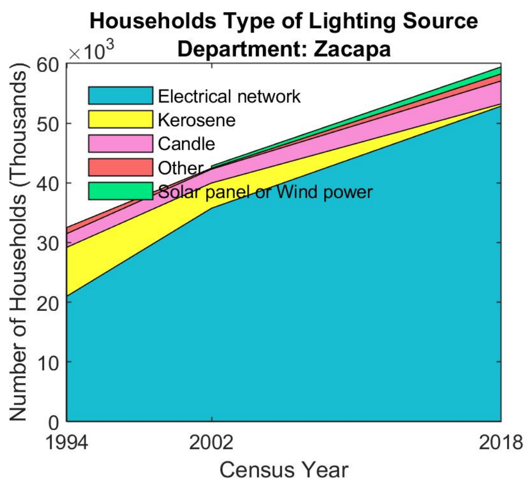


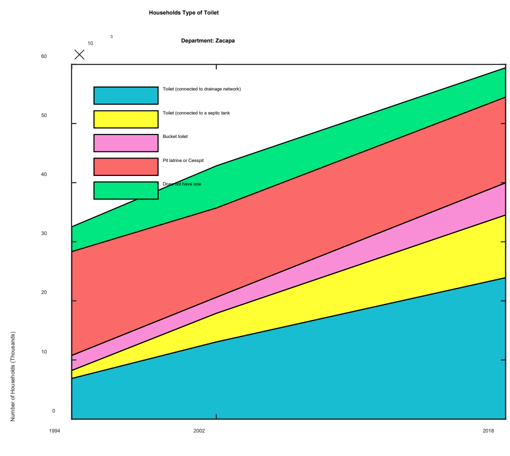
Type of dwelling
Department: Izabal
House
Apartment
Subletting Room in a house
Rancho
Slum Dwelling / Improvised
Other
Ignored
Number of Households (Thousands)
Census Year

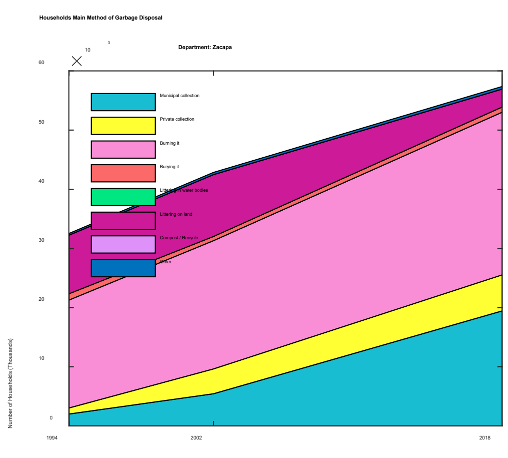
A.2.19. Zacapa

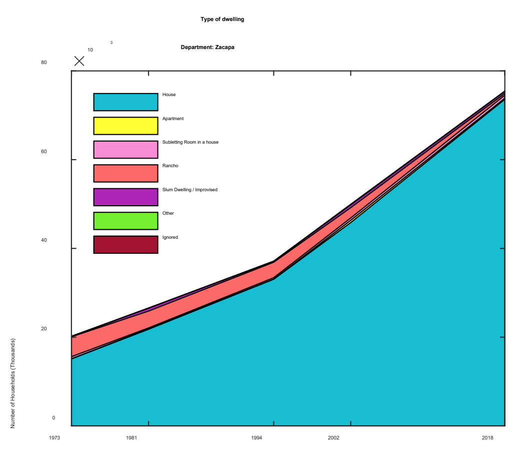

Households Main Source of Energy For Cooking
Department: Zacapa
×10³
Propane gas
Firewood (Leña)
Electricity
Charcoal
Kerosene
Does not cook
Other
Number of Households (Thousands)
0
10
20
30
40
50
60
1994
2002
2018
Census Year


Type of drinking water supply
Department: Zacapa
×10³
Pipeline (for one house)
Pipeline (for +2 houses)
Public tap
Well
Rainwater
River or Lake
Spring
Potable Water Delivery
Other
Number of Households (Thousands)
0
10
20
30
40
50
60
1981
1994
2002
2018
Census Year

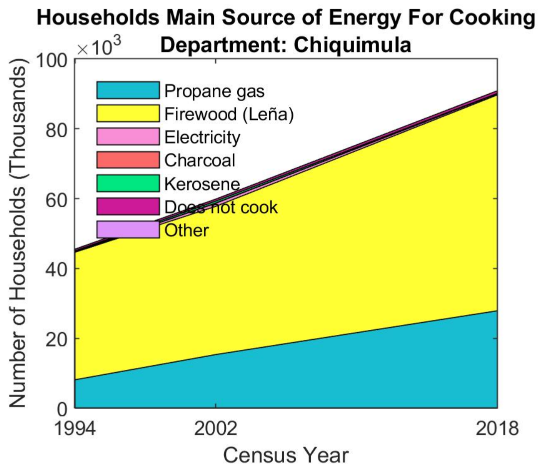

Households Type of Lighting Source
Department: Zacapa
×10³
Electrical network
Kerosene
Candle
Other
Solar panel or Wind power
Number of Households (Thousands)
0
10
20
30
40
50
60
1994
2002
2018
Census Year

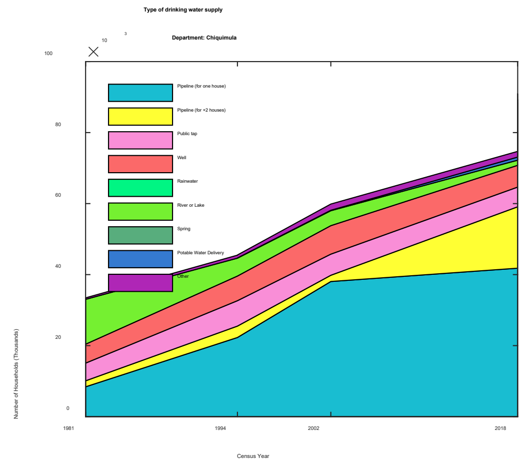

Households Type of Toilet
Department: Zacapa
×10³
Toilet (connected to drainage network)
Toilet (connected to a septic tank
Bucket toilet
Pit latrine or Cesspit
Does not have one
Number of Households (Thousands)
0
10
20
30
40
50
60
1994
2002
2018
Census Year

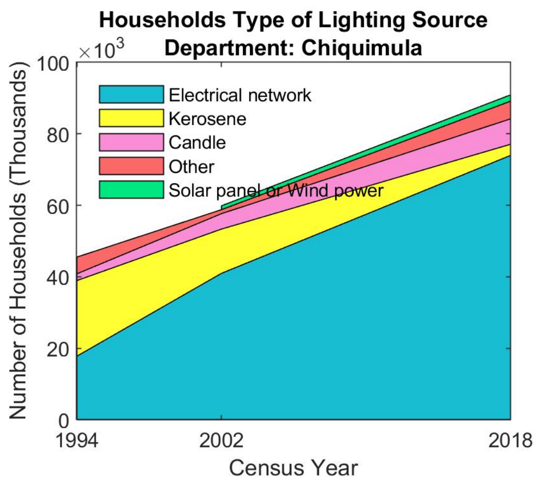

Households Main Method of Garbage Disposal
Department: Zacapa
×10³
Municipal collection
Private collection
Burning it
Burying it
Littering in water bodies
Littering on land
Compost / Recycle
Other
Number of Households (Thousands)
0
10
20
30
40
50
60
1994
2002
2018
Census Year

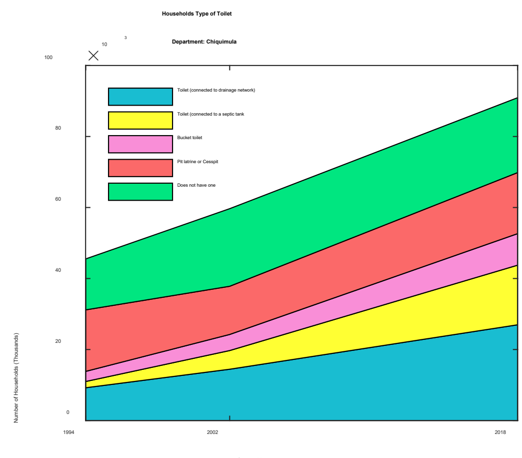

Type of dwelling
Department: Zacapa
×10³
House
Apartment
Subletting Room in a house
Rancho
Slum Dwelling / Improvised
Other
Ignored
Number of Households (Thousands)
0
20
40
60
80
1973
1981
1994
2002
2018
Census Year

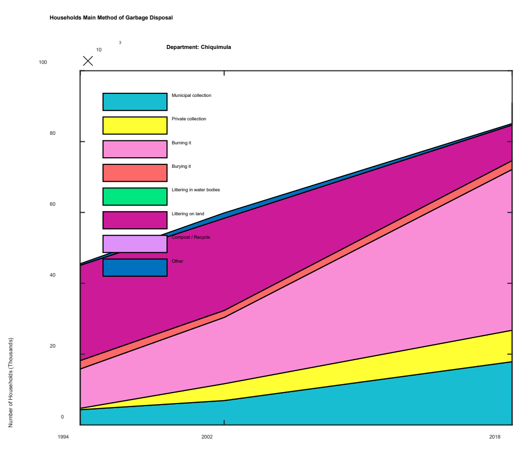
A.2.20. Chiquimula

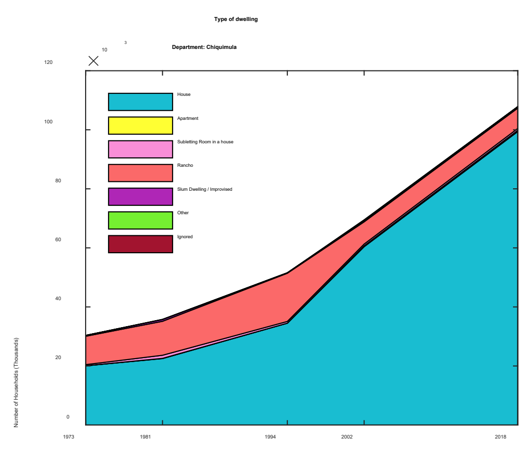




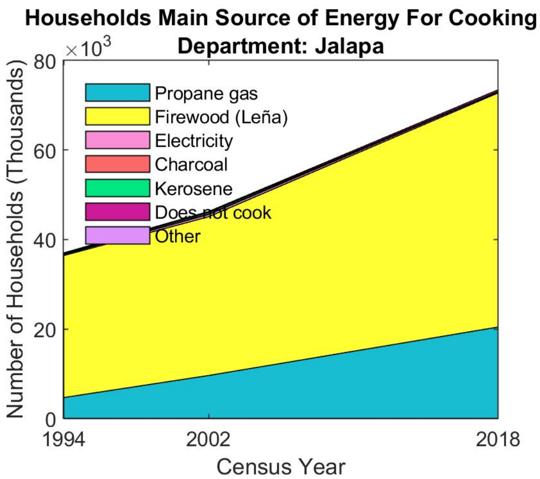




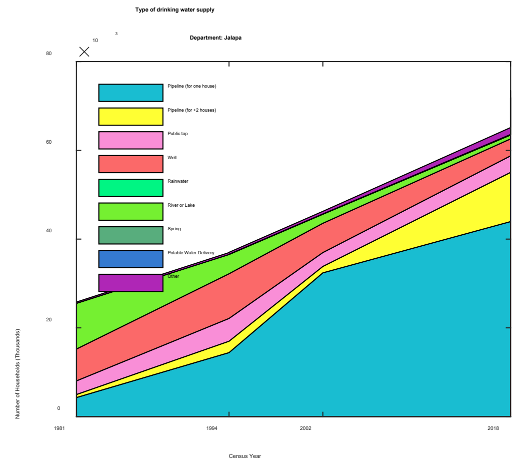




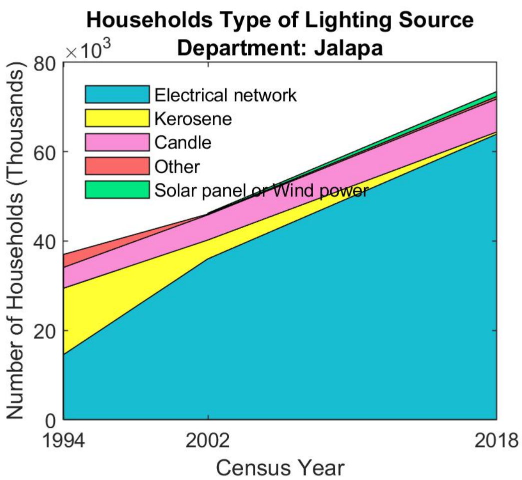
A.2.21. Jalapa



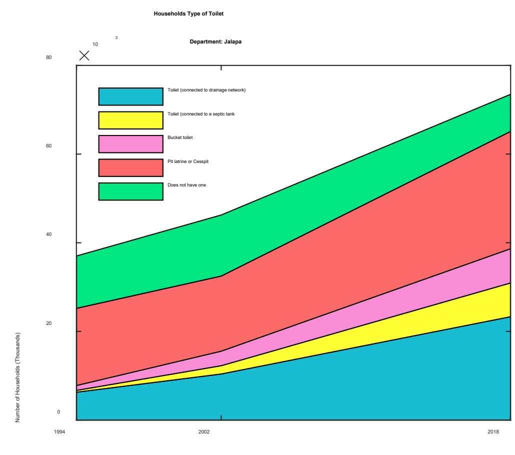
Households Main Source of Energy For Cooking
Department: Jalapa
×10^3
Propane gas
Firewood (Leña)
Electricity
Charcoal
Kerosene
Does not cook
Other
Number of Households (Thousands)
0
20
40
60
80
1994
2002
2018
Census Year



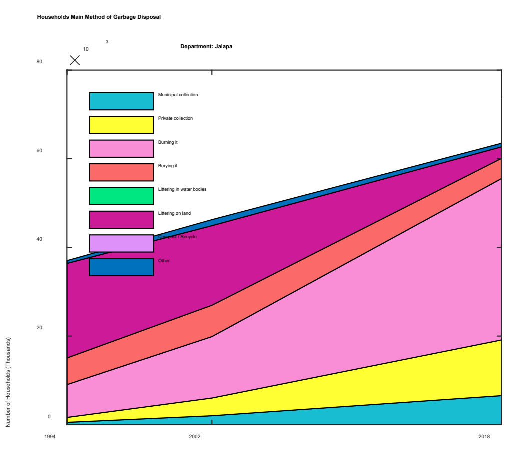
Type of drinking water supply
Department: Jalapa
Pipeline (for one house)
Pipeline (for +2 houses)
Public tap
Well
Rainwater
River or Lake
Spring
Potable Water Delivery
Other
Number of Households (Thousands)
Census Year



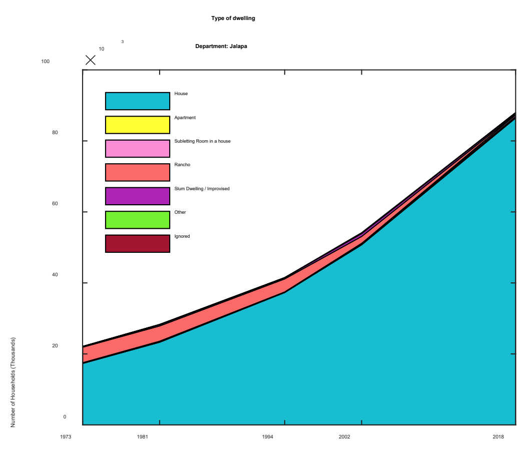
Households Type of Lighting Source
Department: Jalapa
×10^3
Electrical network
Kerosene
Candle
Other
Solar panel or Wind power
Number of Households (Thousands)
0
20
40
60
80
1994
2002
2018
Census Year



Households Type of Toilet
Department: Jalapa
Pit latrine or Cesspit
Does not have one
Number of Households (Thousands)
Census Year

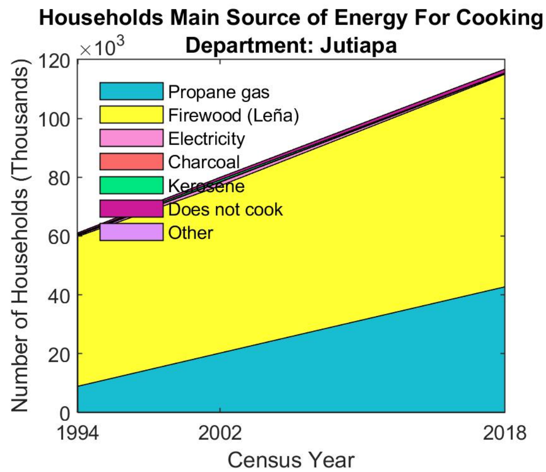


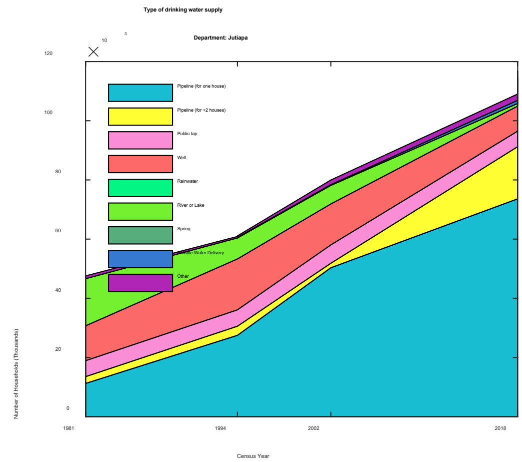
Households Main Method of Garbage Disposal
Department: Jalapa
Municipal collection
Private collection
Burning it
Burying it
Littering in water bodies
Littering on land
Other
Number of Households (Thousands)
Census Year

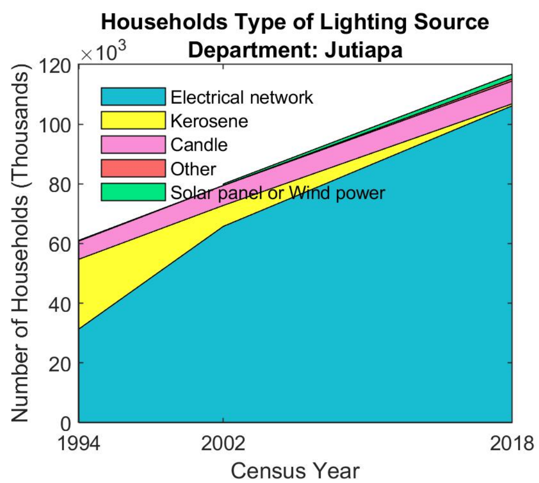


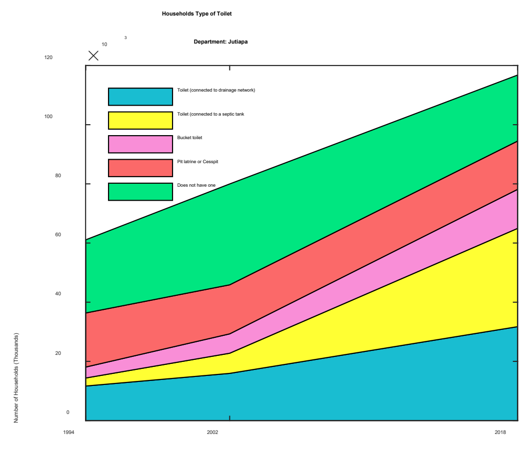
Type of dwelling
Department: Jalapa
House
Apartment
Subletting Room in a house
Rancho
Slum Dwelling / Improvised
Other
Ignored
Number of Households (Thousands)
Census Year

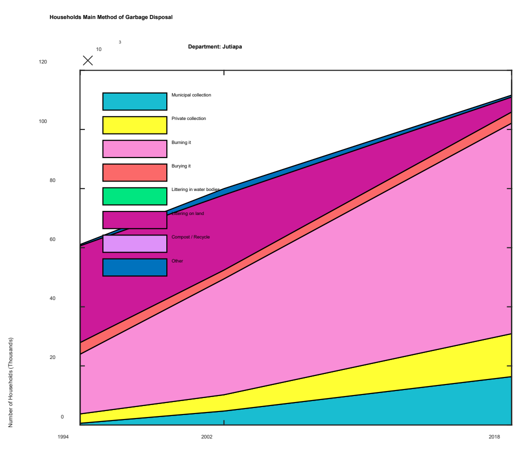
A.2.22. Jutiapa

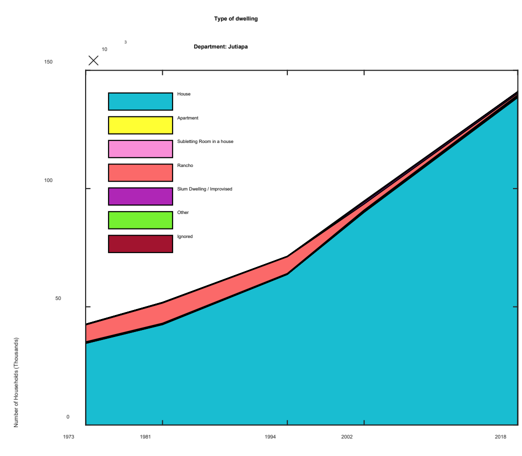












Appendix B. Table used to plan and monitor the censuses digitization

Census (Year)	Type of File	File Name	Pages needed (of the pdf file, not the document)	Category (by Department)	Has the page been		Digitizer	Digitization Methdo	Special Instructions
					Yes	No			
2002	PDF	Census_2002_Documento_Oficial	67	Population	X		Calvin Penaflor	Pdf export to excel	
			163	Dwelling and Housing	X		Calvin Penaflor	Pdf export to excel	
			179	Water Access / Housing	X		Calvin Penaflor	Pdf export to excel	
			187	Energy type / Housing	X		Calvin Penaflor	Pdf export to excel	
			195	Accesibility / Housing	X		Calvin Penaflor	Pdf export to excel	
			203	Garbage Disposal / Economic Activity / Housing	X		Calvin Penaflor	Pdf export to excel	
			211	Housing / Dwelling	X		Calvin Penaflor	Pdf export to excel	
			219	Housing / Dwelling	X		Calvin Penaflor	Pdf export to excel	
			227	Dwelling material (Walls)	X		Calvin Penaflor	Pdf export to excel	
			235	Dwelling material (Roofs)	X		Calvin Penaflor	Pdf export to excel	
			243	Dwelling material (Floor)	X		Calvin Penaflor	Pdf export to excel	
			Bonus: 51-64	Tables comparing 1981, 1994, and 2002 censuses (information about housing and	X		Calvin Penaflor	Pdf export to excel	
1994	.txt	ine11	table 1: (p. 1 to 2)	Household number and occupancy condition	X		Calvin Penaflor		
			table 2: (p. 3 to 4)	Dwelling number and type	X		Calvin Penaflor		
			table 3: (p. 5 to 6)	Dwelling / predominant material on walls	X		Calvin Penaflor		
			table 4: (p.11 to 22)	Dwelling / water access, sewage, and electricity	X		Calvin Penaflor		
			table 5: (p.23 to 24)	Dwelling / predominant material on walls and floor (at a national level)	X		Calvin Penaflor		
	.txt	ine12	table 1: just at a national level (Republica)	Dwelling / type of water service	X		Calvin Penaflor		
			table 2: just at a national level (Republica)	Dwelling / toilet type	X		Calvin Penaflor		
			table 3: just at a national level (Republica)	Dwelling / garbage disposal type	X		Calvin Penaflor		
			table 4: just at a national level (Republica)	Dwelling / kitchen and cooking medium	X		Calvin Penaflor		
			table 5: just at a national level (Republica)	Dwelling / illumination type	X		Calvin Penaflor		
1981	Textbook		25 - 33	Dwelling type	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	*The 1981 census mixes the departments and municipalities data, therefore, depuration is needed in order to extract just the departments information. **I will not need the urban/rural differentiation of the information since there is no homogenity with the other census (i.g. 2002 Census didn't register the dwellings as urban or rural).
			52 - 60	Dwelling occupancy	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			79, 82, 85, 88, 91, 94, 97, 100, 103, 106, 109, 112, 115 118, 121, 124, 127 130, 133, 136, 139 142, 145	Dwelling type (materials on walls and roof)	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			148, 151, 154, 157 160, 163, 166, 169 172, 175, 178, 181 184, 187, 190, 193 196, 199, 202, 205 208, 211, 214	Dwelling type (materials on walls and floor)	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			217 to 283 (every 3 pages; I'm just interested in TOTAL data, and not the urban or rural sub-classifications).	Dwellyg type, wall material and construction year (before and after the 1976 Earthquake)	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			294 - 316	Dwelling type, occupancy, water access, sewage, electricity	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			364 - 409	Dwelling type, occupied housing (with 1, with 2 or more), room number, residents per room	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	

			412 - 478 (every 3 pages; I'm just interested in TOTAL data, and not the urban or rural sub-classifications).	Dwelling type, housing, room number, residents per room	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			481 - 547 (every 3 pages; I'm just interested in TOTAL data, and not the urban or rural sub-classifications).	Dwellling type, bedroom number	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	Compare this two datasets and decide what to execute in case both of them provide the same information
			550 - 616 (every 3 pages; I'm just interested in TOTAL data, and not the urban or rural sub-classifications).	Dwellling type, bedroom number and residents per bedroom	X		Sergio García / Madeline Ramey		
			619 - 626	Dwelling type, water access type	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			627 - 649	Dwelling type, toilet type	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			650 - 672	Dwelling type, kitchen, cooking energy material	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			673 - 680	Dwelling type, illumination	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			681 - 692	Dweling type, head of the house	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			693 - 715	Dweling type, economic activity	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			741 - 744	Collective housing	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			745 - 747	Collective housind dwelling type and number of residents	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
1973	Textbook		3 - 69 (every 3)	Dwelling type (materials on walls and roof)	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	*If item has only 3 pages --> country lvl
			72 - 138 (every 3)	Occupied dwelling by type and wall and roofs material	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			141 - 143	Occupied dwelling by type and wall and floor material	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			144 - 212 (every 3)	Occupied dwelling by type / wall / construction year	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			213 - 215	Occupied dwelling by type / wall / room(s) number	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			216 - 218	Occupied dwelling by type / construction year / room(s) number	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			219 - 356 (select carefully just TOTAL not urban or rural)	Occupied dwelling by type / dwelling installations (water, sewage, electricity, ilumination) and residents	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			357 - 381	Dwelling type / Household number and number of residents per household	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			382 - 384	Occupied dwelling type / number of household residents + rooms number	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			385 - 387	Occupied dwelling type / wall materials + construction year	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			388 - 390	Occupied dwelling type connected to a sewage network / wall materials + construction year	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			391 - 393	Occupied dwelling type connected to electric network / wall materials + construction year	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			394 - 462 (every 3)	Inoccupied dwelling, cause of inoccupancy, wall material	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			463 - 600 (every 3)	number of household residents + rooms number by dwelling type	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	
			601 - 603	Number of rooms, number of bedrooms, by dwelling type	X		Sergio García / Madeline Ramey	Scan pages and pdf to excel	

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